

Debris/Ice/TPS Assessment and Integrated Photographic Analysis of Shuttle Mission STS-92

Gregory N. Katnik

Debris/Ice/TPS Assessment and Integrated Photographic Analysis of Shuttle Mission STS-92

Gregory N. Katnik

*Processing Engineering/Mechanical System Division/ET-SRB Branch,
Kennedy Space Center, Florida*


**DEBRIS/ICE/TPS ASSESSMENT
AND
INTEGRATED PHOTOGRAPHIC ANALYSIS
OF
SHUTTLE MISSION STS-92**

11 October 2000

Contributions By:

NASA, United Space Alliance,
Lockheed-Martin, Boeing Reusable Space Systems, and Thiokol Members of the
Debris/Ice/TPS and Photographic Analysis Teams

Approved:


Gregory N. Katnik
Shuttle Ice/Debris Systems
NASA - KSC
Mail Code: PH-H2



Peter Chitko
Chief, ET/SRB Mechanical Branch
NASA - KSC
Mail Code: PH-H2

TABLE OF CONTENTS

| | |
|--|-----|
| TABLE OF CONTENTS..... | I |
| TABLE OF FIGURES | II |
| TABLE OF PHOTOS | III |
| FOREWORD | IV |
| 1.0 SUMMARY OF SIGNIFICANT EVENTS | 2 |
| 2.0 PRE-LAUNCH SSV/PAD DEBRIS INSPECTION..... | 3 |
| 3.0 SCRUB | 4 |
| 3.1 PRE-LAUNCH SSV/PAD DEBRIS INSPECTION | 4 |
| 3.2 FINAL INSPECTION | 4 |
| 3.3 DRAIN INSPECTION | 8 |
| 4.0 LAUNCH..... | 9 |
| 4.1 PRE-LAUNCH SSV/PAD DEBRIS INSPECTION | 9 |
| 4.2 FINAL INSPECTION | 9 |
| 4.2.1 ORBITER..... | 9 |
| 4.2.2 SOLID ROCKET BOOSTERS | 9 |
| 4.2.3 EXTERNAL TANK..... | 9 |
| 4.2.4 FACILITY | 10 |
| 4.3 T-3 HOURS TO LAUNCH..... | 10 |
| 5.0 POST LAUNCH PAD DEBRIS INSPECTION | 15 |
| 6.0 FILM REVIEW..... | 17 |
| 6.1 LAUNCH FILM AND VIDEO SUMMARY | 17 |
| 6.2 ON-ORBIT FILM AND VIDEO SUMMARY | 20 |
| 6.3 LANDING FILM AND VIDEO SUMMARY | 20 |
| 7.0 SRB POST FLIGHT/RETRIEVAL DEBRIS ASSESSMENT..... | 21 |
| 8.0 ORBITER POST LANDING DEBRIS ASSESSMENT..... | 27 |
| APPENDIX A. JSC PHOTOGRAPHIC ANALYSIS SUMMARY..... | A |
| APPENDIX B. MSFC PHOTOGRAPHIC ANALYSIS SUMMARY..... | B |

TABLE OF FIGURES

| | |
|---|----|
| Figure 1: Orbiter Lower Surface Debris Damage Map | 29 |
| Figure 2: Orbiter Right Side Debris Damage Map..... | 30 |
| Figure 3: Orbiter Left Side Debris Damage Map | 31 |
| Figure 4: Orbiter Upper Surface Debris Damage Map..... | 32 |
| Figure 5: Orbiter Post Flight Debris Damage Summary | 33 |

TABLE OF PHOTOS

| | |
|--|----|
| Photo 1: Launch of Shuttle Mission STS-92..... | 1 |
| Photo 2: T-Handle Ball Lock Pin..... | 5 |
| Photo 3: T-Handle Ball Lock Pin..... | 6 |
| Photo 4: T-Handle Ball Lock Pin..... | 7 |
| Photo 5: External Tank After Cryoload..... | 11 |
| Photo 6: LH2 ET/ORB Umbilical..... | 12 |
| Photo 7: +Y Longerons..... | 13 |
| Photo 8: SSME #2..... | 14 |
| Photo 9: Aft Skirt GN2 Purge Lines..... | 16 |
| Photo 10: SRB Stud Hang-ups..... | 19 |
| Photo 11: Frustum Post Flight Condition..... | 22 |
| Photo 12: Forward Skirt Post Flight Condition..... | 23 |
| Photo 13: Aft Skirt Post Flight Condition..... | 24 |
| Photo 14: Broaching Due to Stud Hang-ups..... | 25 |
| Photo 15: Crack in Cork Closeout..... | 26 |
| Photo 16: Overall View of Orbiter Sides..... | 34 |
| Photo 17: Damage to Lower Surface Tiles..... | 35 |
| Photo 18: Tile Damage Near Umbilicals..... | 36 |
| Photo 19: Hairline Cracks in Thermal Blankets..... | 37 |
| Photo 20: Rudder/Speed Brake Spring Clip..... | 38 |
| Photo 21: LO2 ET/ORB Umbilical..... | 39 |
| Photo 22: LH2 ET/ORB Umbilical..... | 40 |
| Photo 23: Windows..... | 41 |
| Photo 24: Debris Found on Runway..... | 42 |

FOREWORD

The Debris Team has developed and implemented measures to control damage from debris in the Shuttle operational environment and to make the control measures a part of routine launch flows. These measures include engineering surveillance during vehicle processing and closeout operations, facility and flight hardware inspections before and after launch, and photographic analysis of mission events.

Photographic analyses of mission imagery from launch, on-orbit, and landing provide significant data in verifying proper operation of systems and evaluating anomalies. In addition to the Kennedy Space Center Photo/Video Analysis, reports from Johnson Space Center and Marshall Space Flight Center are also included in this document to provide an integrated assessment of the mission.



Photo 1: Launch of Shuttle Mission STS-92

1.0 SUMMARY OF SIGNIFICANT EVENTS

STS-92 consisted of OV-103 Discovery (28th flight), ET-104, and BI-104 SRB's on MLP-3 and Pad 39A. Discovery was launched at 285:23:17:00.011 UTC (7:17 p.m. local) on 11 October 2000. Landing was at 1:59 pm local/pacific time on 24 October 2000.

The vehicle was cryoloaded for flight on 10 October 2000. During the Final Inspection at T-3 hours, a T-handle ball lock pin resting on the TPS closeout of the LO2 feedline inboard support bracket was discovered. Since the pin could not be safely removed from the vehicle while the ET was loaded, the launch attempt was scrubbed. After ET drain, the RSS was extended and the pin removed. At that time, a small area, 0.25-inches x 0.25-inches x 0.125-inch depth, of damaged foam caused by the T-handle was documented on a PR and dispositioned to use-as-is with no repair required. Since the pin had fallen from a higher-level access platform, a more extensive inspection of the vehicle was performed. But no other damaged TPS was found.

For only the second time in the Program history, two SRB stud hang-ups occurred (the data base showed STS-2, holddown posts #6 and #8). The STS-92 hang-ups occurred on HDP #2 and #4. The pattern was similar for both posts - the stud was held fully extended until the aft skirt foot was clear. Then the stud twanged briefly before falling into the holddown post. A piece of shaved aluminum from the bore fell with the stud.

As expected, broaching occurred in the holddown stud bores of posts #2 and #4 consistent with stud hang-ups seen in the post launch film reviews. Both broached areas were generally on the +Z side of the bore, though only #2 had stud thread impressions as well. The DCS #2 plunger was obstructed by a frangible nut piece while the #4 plunger was seated.

A 2.5-inch long (circumferential) by 1-inch deep crack in the cork closeout was detected in the RH SRB center field joint leading edge at approximately 220 degrees. Sooting was visible adjacent to the crack as well as inside the crack to a point about half the depth. Although some of the Hypalon paint was missing at this location, no obvious signs of impact by debris objects were noted. This was the third occurrence in RSRM history (STS-61, -94, and -92) with all cracks on the RH center field joint closeout between 200-220 degrees. Post flight testing of cork impacts along with debris trajectory analysis concluded the cracks were caused by impacts from pieces of ice from the External Tank LO2 feedline upper bellows.

Post landing inspection of Orbiter tiles showed a total of 127 hits, of which 24 had a major dimension of 1-inch or larger. The Orbiter lower surface sustained 86 total hits, of which 14 had a major dimension of 1-inch or larger. Approximately 33 damage sites (with three larger than 1-inch in length) were located in the area from the nose gear to the main landing gear wheel wells. The majority of this damage occurred on the right-hand side of the vehicle, though some of these hits may be attributed to impacts from ice in the LO2 feedline bellows. ET TPS venting modifications continue to have a reducing effect on the quantity and size of the damage sites.

The largest lower surface tile damage site, located on the right wing just outboard of the LO2 umbilical door, measured 2-inches long by 1-inch wide by 0.75-inches deep. The cause of this damage site is believed to be ice from the ET LO2 feedline bellows.

In summary, both the total number of Orbiter TPS debris hits and the number of hits 1-inch or larger were somewhat greater than the fleet averages. But in general, the lower surface tile damage on this flight was considered to be a return to fleet averages, or "in family". Missions STS-86 through STS-103 are considered an "out of family" set due to the loss of TPS from External Tank thrust panels.

2.0 PRE-LAUNCH SSV/PAD DEBRIS INSPECTION

The Debris/Ice/TPS and Photographic Analysis Team briefing for launch activities was conducted at 1500 on 5 October 2000. The following personnel participated in various team activities, assisted in the collection and evaluation of data, and contributed to reports contained in this document.

| | | |
|--------------|------------|---------------------------------------|
| G. Katnik | NASA - KSC | Shuttle Ice/Debris Systems |
| R. Speece | NASA - KSC | Thermal Protection Systems |
| J. Rivera | NASA - KSC | ET Mechanisms/Structures |
| W. Boyter | NASA - KSC | SRB Mechanical Systems |
| B. Nguyen | NASA - KSC | SRB Mechanical Systems |
| R. Page | NASA - KSC | SSP Integration |
| K. Leggett | USA - SFOC | Supervisor, ET/SRB Mechanical Systems |
| J. Blue | USA - SFOC | ET Mechanical Systems |
| W. Richards | USA - SFOC | ET Mechanical Systems |
| M. Wollam | USA - SFOC | ET Mechanical Systems |
| T. Ford | USA - SFOC | ET Mechanical Systems |
| R. Seale | USA - SFOC | ET Mechanical Systems |
| R. Brewer | USA - SFOC | ET Mechanical Systems |
| R. Oyer | Boeing | Systems Integration |
| C. Hill | Boeing | Systems Integration |
| D. Leggett | Boeing | Systems Integration |
| Mike Nowling | THIO - LSS | SRM Processing |
| S. Otto | LMMSS | ET Processing |
| J. Ramirez | LMMSS | ET Processing |

3.0 SCRUB

3.1 PRE-LAUNCH SSV/PAD DEBRIS INSPECTION

A pre-launch debris inspection of the launch pad and Shuttle vehicle was performed on 9 October 2000. The walkdown of Pad 39A and MLP-3 included the flight elements OV-103 Discovery (28th flight), ET-104, and BI-104 SRB's. There were no significant SSV discrepancies. Two items as potential debris were entered in OMI S0007 Appendix K for resolution prior to cryoload:

1. Four loose bolts/nuts on both east and west MLP deck safety shower support brackets
2. Thin wire approximately 4 inches in length on the Orbiter Access Arm white room roof

A bolt and a shackle identification tag found on the MLP near the sound suppression water pipe were taken to the Pad Leader for disposition.

In addition, IPR 092V-0105 was taken against eroded ET TPS coming in contact with the LD54/55 tygon tubes buffeted by high winds. Closer inspection from the -Y OWP access platform revealed superficial damage (less than 1/8-inch depth) from the chafing to areas on the -Y vertical strut and upper strut fairing. The IPR was upgraded to PR ET-104-TS with MRB approval to use-as-is.

3.2 FINAL INSPECTION

The Final Inspection of the cryoloaded vehicle was performed on 10 October 2000 from 1500 to 1730 hours during the two hour built-in-hold at T-3 hours in the countdown. There were no Launch Commit Criteria (LCC) or OMRS criteria violations. IPR 092V-0109 was taken for a T-handle ball lock pin resting on the TPS closeout of the LO2 feedline inboard support bracket. Since the pin could not be safely removed from the vehicle while the ET was loaded, the launch attempt was scrubbed. After ET drain, the RSS was extended and the pin removed. At that time, a small area, 0.25-inches x 0.25-inches x 0.125-inch depth, of damaged foam caused by the T-handle was documented on a PR and dispositioned to use-as-is with no repair required. Since the pin had fallen from a higher-level access platform, a more extensive inspection of the vehicle was performed. But no other damaged TPS was found.

While the External Tank was cryoloaded, the TPS was dry with no condensate forming in the usual places. Surface temperatures ranged from 57 to 61 degrees F. There were no acreage icing concerns. There were also no protuberance icing conditions outside of the established database. A total of fourteen cracks in intertank stringer valley TPS, including two between the bipods, were observed. The length, width, and general characteristics of the cracks did not exceed conditions already documented on previous vehicles and were considered acceptable for flight. No anomalies on the SRB's or the launch pad were detected. On the Orbiter, no problems occurred with the thermal protection tiles or RCC panels. The SSME's were in nominal configuration. The paper covers on RCS thrusters F3L, L1L, and R2R were discolored.

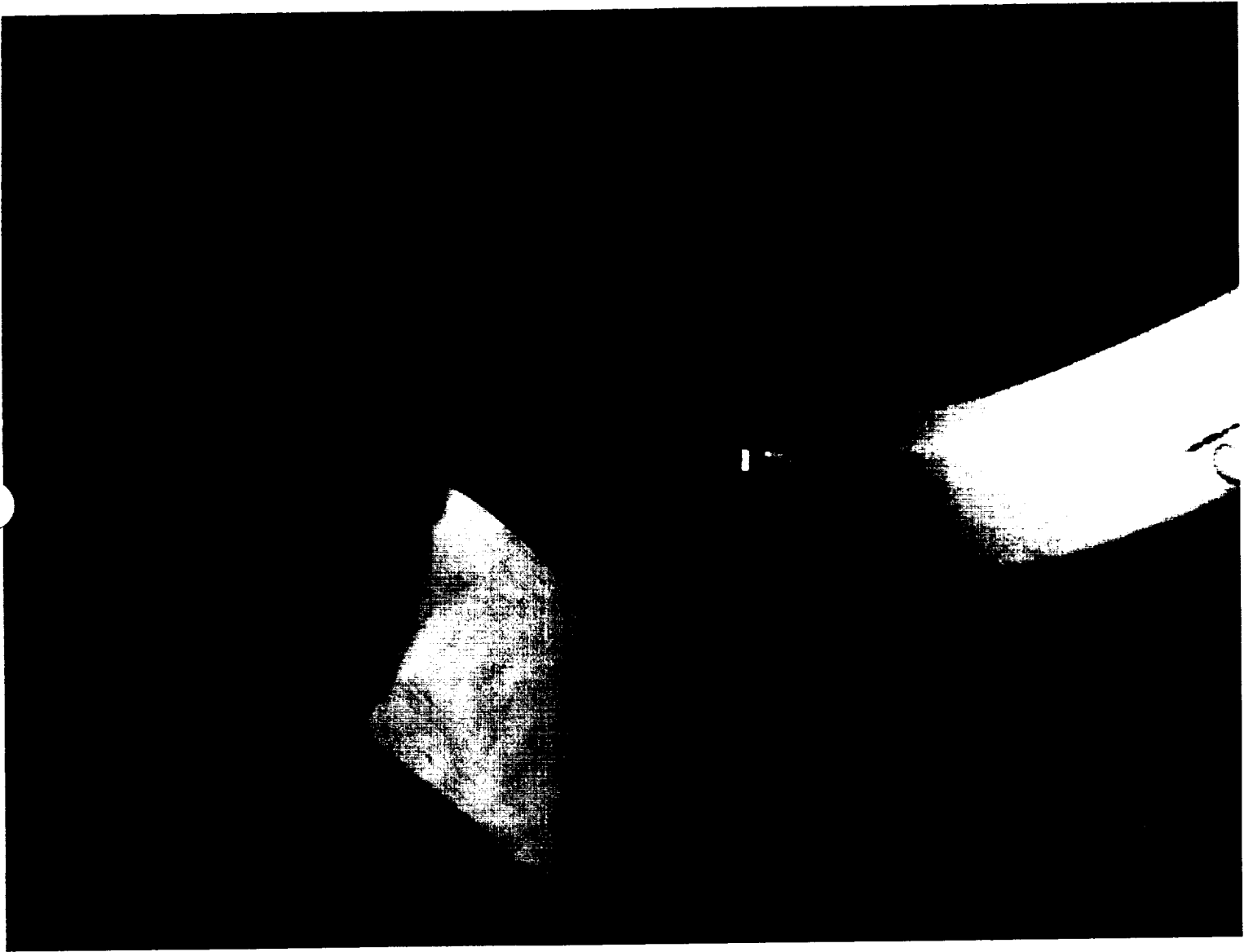


Photo 2: T-Handle Ball Lock Pin

T-handle ball lock pin lying on LO2 feedline inboard support bracket TPS closeout



Photo 3: T-Handle Ball Lock Pin

A small area, 0.25-inches x 0.25-inches x 0.125-inch depth, of damaged foam caused by the T-handle was documented on a PR and dispositioned to use-as-is with no repair required. Since the pin had fallen from a higher-level access platform, a more extensive inspection of the vehicle was performed. But no other damaged TPS was found.



Photo 4: T-Handle Ball Lock Pin
T-handle ball lock pin with tether

3.3 DRAIN INSPECTION

The post drain inspection of the STS-92 vehicle, MLP-3, and Pad A FSS was conducted on 10-11 October 2000 from 2300 to 0100 hours under dark conditions. Prior to leaving LCC Firing room 2, the team was notified that the Pad xenon lights would be turned off to support an early Rotating Service Structure extension for IPR-0109 retrieval of T-handle ball lock pin from the inboard ET LO2 feedline support bracket. The inspection was completed with adequate lighting available.

The GOX vent arm was in the retracted position. OTV monitoring from LCC Firing Room 2 was performed prior to and during GVA retraction and verified no anomalies with the vent system or the ET nose cone and forward LO2 tank TPS. The post detank Pad inspection also verified no anomalies in this area.

No anomalies were observed on the SRB's.

Orbiter wing RCC panels were in nominal configuration. Two small tile gap-fillers protruded from lower surface tiles. FRCS thrusters L1L and R2R RCS paper covers were missing. SSME's and heat shields were in nominal condition.

The External Tank was in excellent condition. All closeouts were in nominal configuration. All PDL repairs were intact with none protruding. No crushed foam or debris was detected in the LO2 feedline support brackets. The stress relief crack in the -Y vertical strut forward facing TPS was visible, but not nearly as pronounced as had been observed with LCC firing room OTV.

The only ice/frost accumulations remaining were located in the LO2 feedline bellows and support brackets, the LH2 ET/ORB umbilical purge barrier, the upper EB fittings, and on the ET/ORB umbilical purge vents.

In summary, no IPR conditions or flight hardware concerns were detected during the post drain inspection. There are no identified constraints for the next cryoload.

4.0 LAUNCH

4.1 PRE-LAUNCH SSV/PAD DEBRIS INSPECTION

A second T-8 hour inspection of the pad and SSV was performed. No new issues or concerns were detected.

4.2 FINAL INSPECTION

The Final Inspection of the cryoloaded vehicle was performed on 11 October 2000 from 1345 to 1500 hours during the two hour built-in-hold at T-3 hours in the countdown. There were no Launch Commit Criteria (LCC) or OMRS criteria violations. There were no acreage icing concerns. There were also no protuberance icing conditions outside of the established database.

A portable Shuttle Thermal Imager (STI) infrared scanning radiometer was utilized to obtain vehicle surface temperature measurements for an overall thermal assessment of the vehicle, particularly those areas not visible from remote fixed scanners, and to scan for unusual temperature gradients.

4.2.1 ORBITER

No Orbiter tile or RCC panel anomalies were observed. The RCS thruster paper covers were intact but three covers (L1L, R2R, and R2D) were discolored. Ice/frost had formed on the SSME #1 and #2 heat shield-to-nozzle interfaces. The SSME #3 heat shield was dry.

4.2.2 SOLID ROCKET BOOSTERS

SRB case temperatures measured by the STI radiometers were close to ambient temperatures. All measured temperatures were above the 34 degrees F minimum requirement.

4.2.3 EXTERNAL TANK

The ice/frost prediction computer program 'SURFICE' was run as a comparison to infrared scanner point measurements.

During this second cryogenic loading, the Final Inspection Team observed light condensate on the LO2 tank acreage. Surface temperatures averaged 61 degrees F. There were no TPS anomalies.

No significant anomalies were present in the intertank TPS. The 14 stringer valley TPS cracks including the two located in between the bipods detected during the previous cryoload had increased to a total of 16. Ice and frost accumulations on the GUCP were typical.

Light condensate was present on the LH2 tank acreage. Surface temperatures ranged from 54 to 65 degrees Fahrenheit. There were no acreage TPS anomalies.

Less than usual amounts of ice/frost had accumulated in the LO2 feedline bellows and support brackets.

Also as expected for a second cryoload, there were numerous small frost spots on various closeout bondlines including two places on the -Y bipod housing ramp and a 1-inch diameter spot on the +Y longeron. The 10-inch dogleg stress relief crack in the -Y vertical strut TPS had not changed significantly since the last cryoload. This condition had been accepted for flight on previous vehicles.

There were no TPS anomalies on the LO2 ET/ORB umbilical. Ice/frost accumulations were present on the aft and inboard sides. Ice/frost fingers on the separation bolt pyrotechnic canister purge vents were typical.

Ice and frost in the LH2 recirculation line bellows and on both burst disks was typical. Likewise, a typical amount of ice/frost had accumulated on the LH2 ET/ORB umbilical purge barrier outboard side, forward, and aft surfaces. Typical ice/frost fingers were present on the pyro canister and plate gap purge vents. No unusual vapors or cryogenic drips had appeared during tanking, stable replenish, and launch.

Overall, the ET was in excellent condition for a second cryogenic loading with no significant changes from the previous tanking.

4.2.4 FACILITY

All SRB sound suppression water troughs were filled and properly configured for launch. No leaks were observed on the GUCP or the LO2 and LH2 Orbiter T-0 umbilicals.

4.3 T-3 HOURS TO LAUNCH

After completion of the Final Inspection on the pad, surveillance continued from the Launch Control Center. Twenty-two remote-controlled television cameras and two infrared radiometers were utilized to perform scans of the vehicle. No ice or frost on the acreage TPS was detected. Protuberance icing previously assessed did not increase. At T-2:30, the GOX vent seals were deflated and the GOX vent hood lifted. Although frost covered some of the ET nose cone louvers - an expected condition - no ice was detected. When the heated purge was removed by retraction of the GOX vent hood, frost continued to form on the louvers until liftoff. At the time of launch, there were no ice accumulations in the "no ice zone".

STS-92 was launched at 285:23:17:00.011 UTC (7:17 p.m. local) on 11 October 2000.

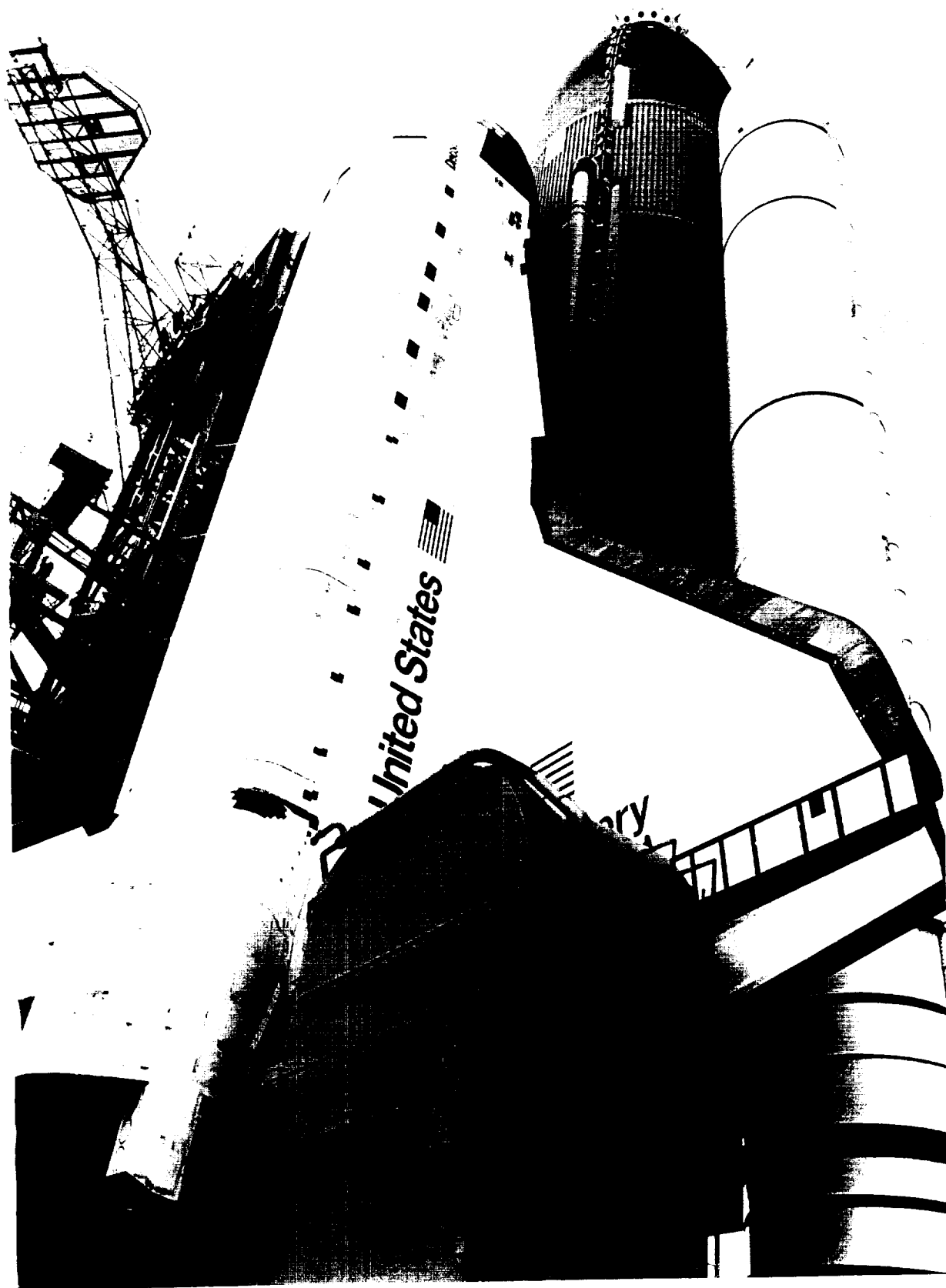


Photo 5: External Tank After Cryoload

During this second cryogenic loading, the Final Inspection Team observed light condensate on the LO₂ and LH₂ tank acreage. Surface temperatures ranged from 54 to 65 degrees F. The 14 stringer valley TPS cracks including the two located in between the bipods detected during the previous cryoload had increased to a total of 16.



Photo 6: LH2 ET/ORB Umbilical

Ice and frost in the LH2 recirculation line bellows and on both burst disks was typical. Likewise, a typical amount of ice/frost had accumulated on the LH2 ET/ORB umbilical purge barrier outboard side, forward, and aft surfaces. Typical ice/frost fingers were present on the pyro canister and plate gap purge vents. No unusual vapors or cryogenic drips had appeared during tanking, stable replenish, and launch.



Photo 7: +Y Longeron

A 1-inch diameter frost ball had formed on the +Y longeron

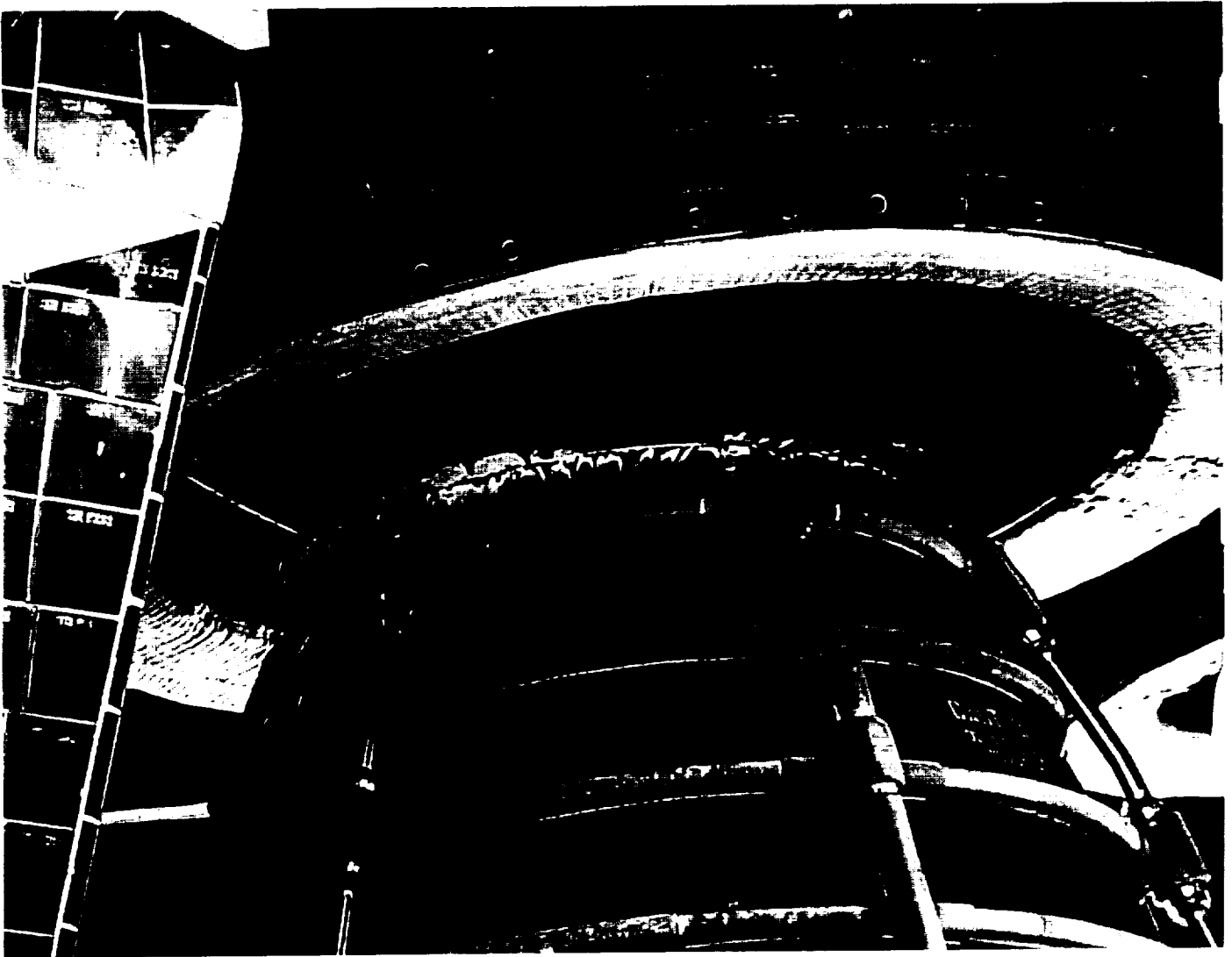


Photo 8: SSME #2

Ice/frost had formed on the SSME #1 and #2 heat shield-to-nozzle interfaces

5.0 POST LAUNCH PAD DEBRIS INSPECTION

The post launch inspection of the MLP-3, Pad A FSS and RSS was conducted on 11 October 2000 from Launch + 2 to 4 hours. No flight hardware was found.

Orbiter liftoff lateral acceleration data to predict stud hang-ups initially received from Boeing-Huntington Beach indicated that no hang-up had occurred. Later revision of the report predicted two stud hang-ups, possibly on HDP #2 and #4. No signs of stud hang-ups were immediately obvious in the visual inspection of the four south posts. Erosion was typical for the south posts. North holddown post blast covers and T-0 umbilical exhibited typical exhaust plume damage. Both SRB aft skirt GN2 purge lines were intact, though the protective tape layering was partially eroded.

The LO2 and LH2 Tail Service Masts (TSM) appeared undamaged and the bonnets were closed properly. The MLP deck was in generally good shape.

The GH2 vent line latched in the eighth of eight teeth of the latching mechanism. The GUCP 7-inch QD sealing surface exhibited no damage, although the probe end showed evidence of contact at the twelve o'clock position. The vent line sustained more than usual plume impingement as indicated by the severe scorching of the vacuum jacketed flex-hose, GUCP housing and electrical wiring. A T-0 lock roller was broken and lying on the deck grating.

The OAA appeared to be intact with no evidence of plume impingement.

Slidewire baskets were secured with no sign of damage.

The GOX vent arm, hood, ducts and structure appeared to be in good shape with no indications of plume damage.

Debris findings included:

- No significant damage in the flame trenches.
- Minimal facility debris, but no flight debris, was found on the Pad apron.
- No unusual debris items were found on the FSS

Overall, damage to the pad appeared to be minimal.

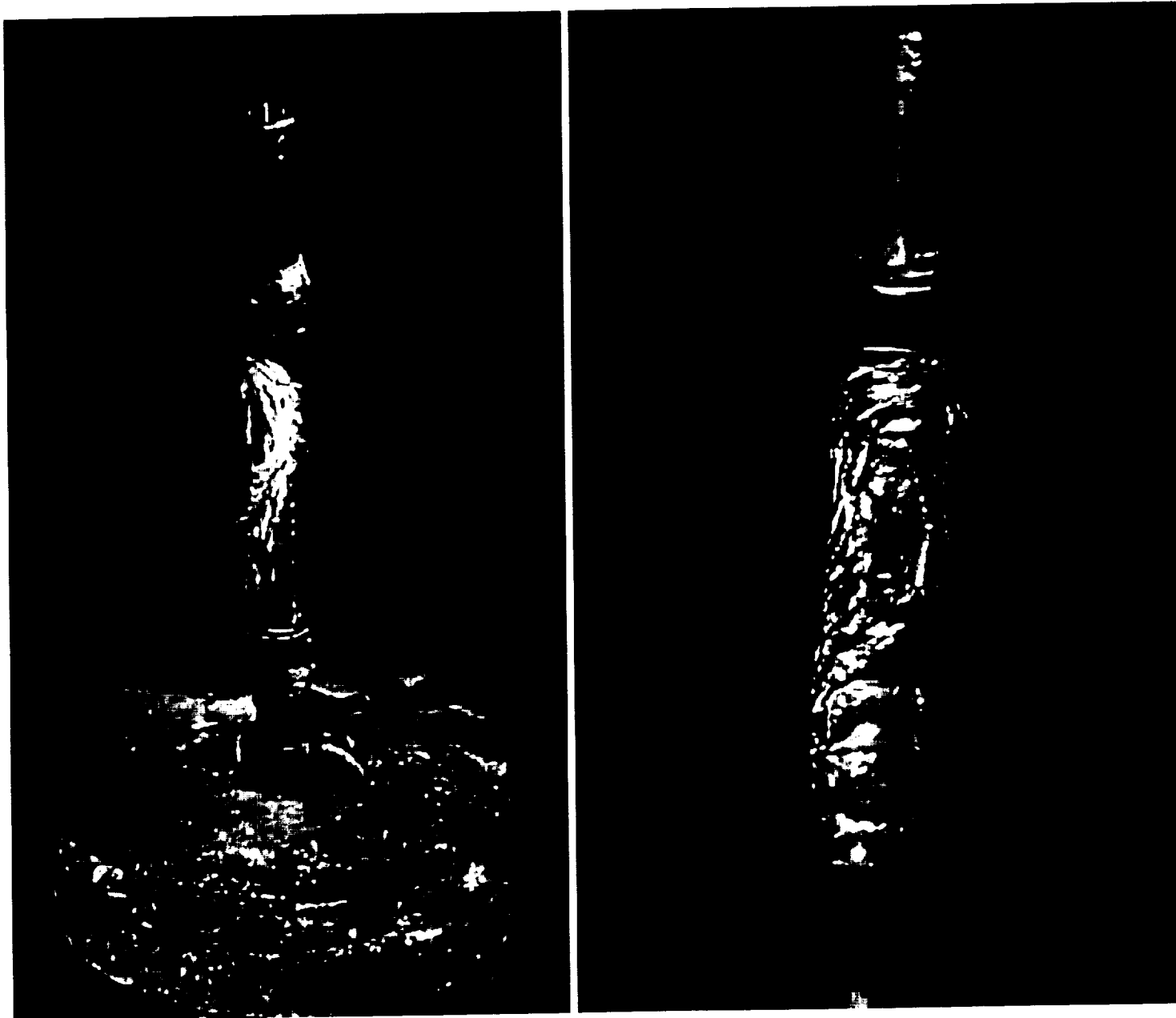


Photo 9: Aft Skirt GN2 Purge Lines

Both SRB aft skirt GN2 purge lines were intact, though the protective tape layering was partially eroded.

6.0 FILM REVIEW

Anomalies observed in the Film Review were reported to the Mission Management Team, Shuttle managers, vehicle systems engineers, and to Program Integration.

6.1 LAUNCH FILM AND VIDEO SUMMARY

A total of 81 films and videos, which included twenty-seven 16mm films, sixteen 35mm films, and thirty-eight videos, were reviewed starting on launch day.

New cameras mounted in the GOX Vent Hood clearly showed no ice or frost formation on the ET louvers during cryogenic loading and stable replenish. Frost, but no ice, formed when the purge was terminated and the hood lifted at T - 2:30.

SSME ignition appeared normal (OTV 051, 070). A considerable amount of free burning hydrogen was visible in the orbiter base heat shield area and rising to the RH OMS pod before dissipating. Three streaks/flashs occurred in the SSME #1 exhaust plume during startup (E-2, -19).

Small pieces of tile surface coating material were shaken loose by SSME ignition acoustics/vibration from seven places on the base heat shield near SSME #3, seven places on the base heat shield near SSME #2, two places on the right OMS heat shield, one place on the right APCS pod, and one place on the left APCS pod (E-17, -18, -19, -20, -31).

Numerous pieces of ice from the ET/ORB umbilicals shook loose and contacted umbilical sill tiles and ET cable tray TPS, but no damage was detected (OTV 009, 063).

A small piece of ice from the SSME nozzle fell and contacted the body flap. Size, mass, and velocity were insufficient to cause tile damage (E-5).

LH2 and LO2 T-0 umbilical disconnect was normal (OTV 049, 050).

GUCP disconnect from the ET was nominal (E-33).

A 1-inch by 1-inch particle fell from lower surface black tiles shortly after liftoff. The particle is believed to be a piece of tile surface coating material or tile repair material that shook loose at ignition and liftoff. The particle appeared to originate from an area between centerline and the left wing glove approximately XO-490. (OTV 061)

A small, non-metallic debris object passed close to the camera lens at 12:04:38.244 (timing not correct as recorded on the film) and was not a threat to flight hardware (E-20).

A small piece of SRB throat plug material ejected out of the SRB exhaust hole at T-0 contacted the -Z side of SSME #3. Size, mass, and velocity were insufficient to cause any damage (E-5).

A rigid piece of debris, believed to be deck scale, contacted the sound suppression pipe at 23:17:01.151 UTC, but did not move in the direction of flight hardware (E-10).

For only the second time in the Program history, two stud hang-ups occurred (the data base showed STS-2, holddown posts #6 and #8). The STS-92 hang-ups occurred on HDP #2 and #4. The pattern was similar for both posts - the stud was held fully extended until the aft skirt foot was clear. Then the stud twanged briefly before falling into the holddown post. A piece of shaved aluminum from the bore fell with the stud (broaching was visible during the SRB Post Flight Assessment).

Both SRB GN2 purge lines separated cleanly from the aft skirt and were in nominal condition until lost from view by smoke (E-8, -13)

More than usual pieces of SRB throat plug were ejected from the exhaust holes and flame trench at T-0, though none contacted the Orbiter (E-63).

Vapors emanating from ET aft dome were caused by TPS outgassing rather than condensate vaporizing (E-52).

Numerous streaks and flashes in the SSME exhaust plumes during early ascent were caused by pieces of RCS thruster paper covers falling aft.

A large particle moved away from the LH SRB aft skirt area just after liftoff (OTV 071). The particle is most likely a piece of SRB throat plug.

Two dark pieces of debris moved south out of the SSME flame trench away from the MLP/SSV at 23:16:59.74 (E-63).

Five light-colored objects fell aft along side the exhaust plume at 69.5, 70, 70.5, 79, and 82.5 seconds MET (TV-5 Video). Two of these could be seen in the TV-21 video at 69 and 70 seconds MET. These objects are believed to be pieces of SRB aft skirt aft ring instafoam.

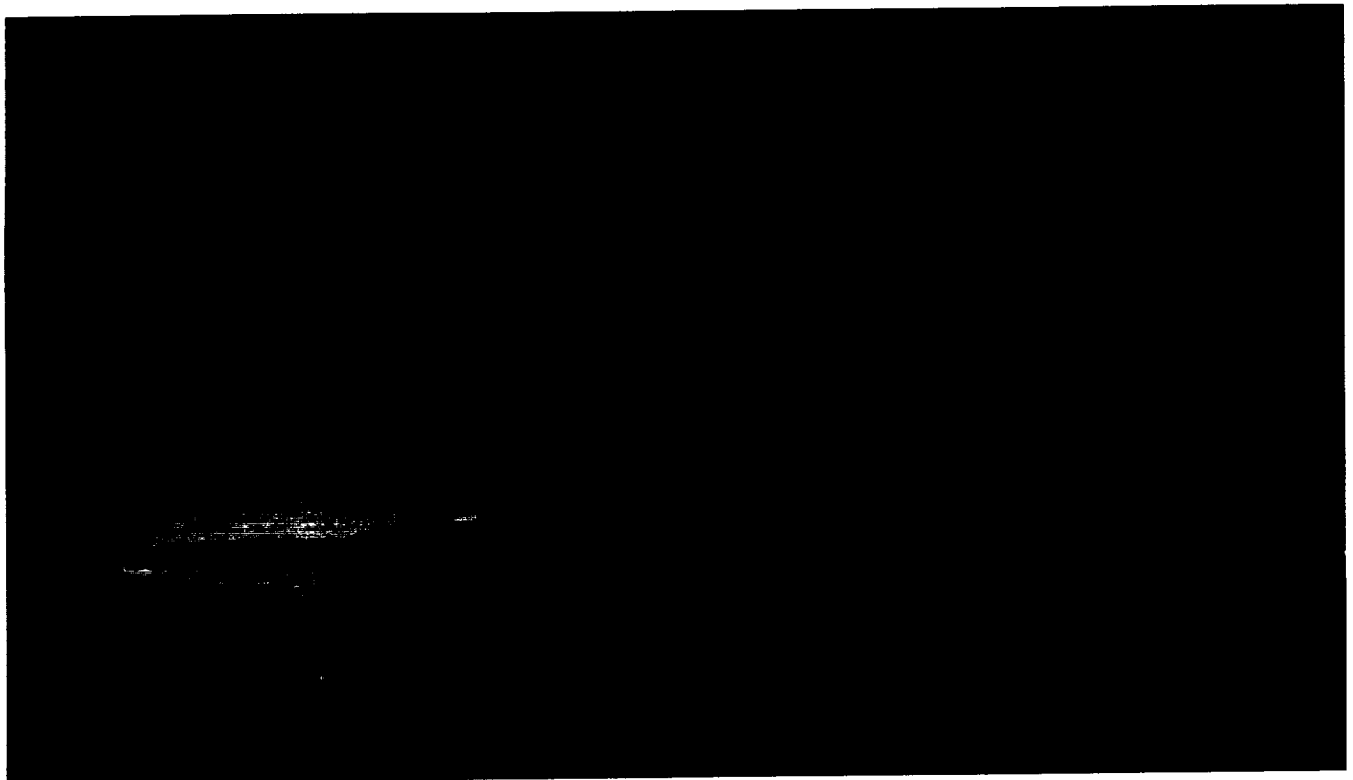
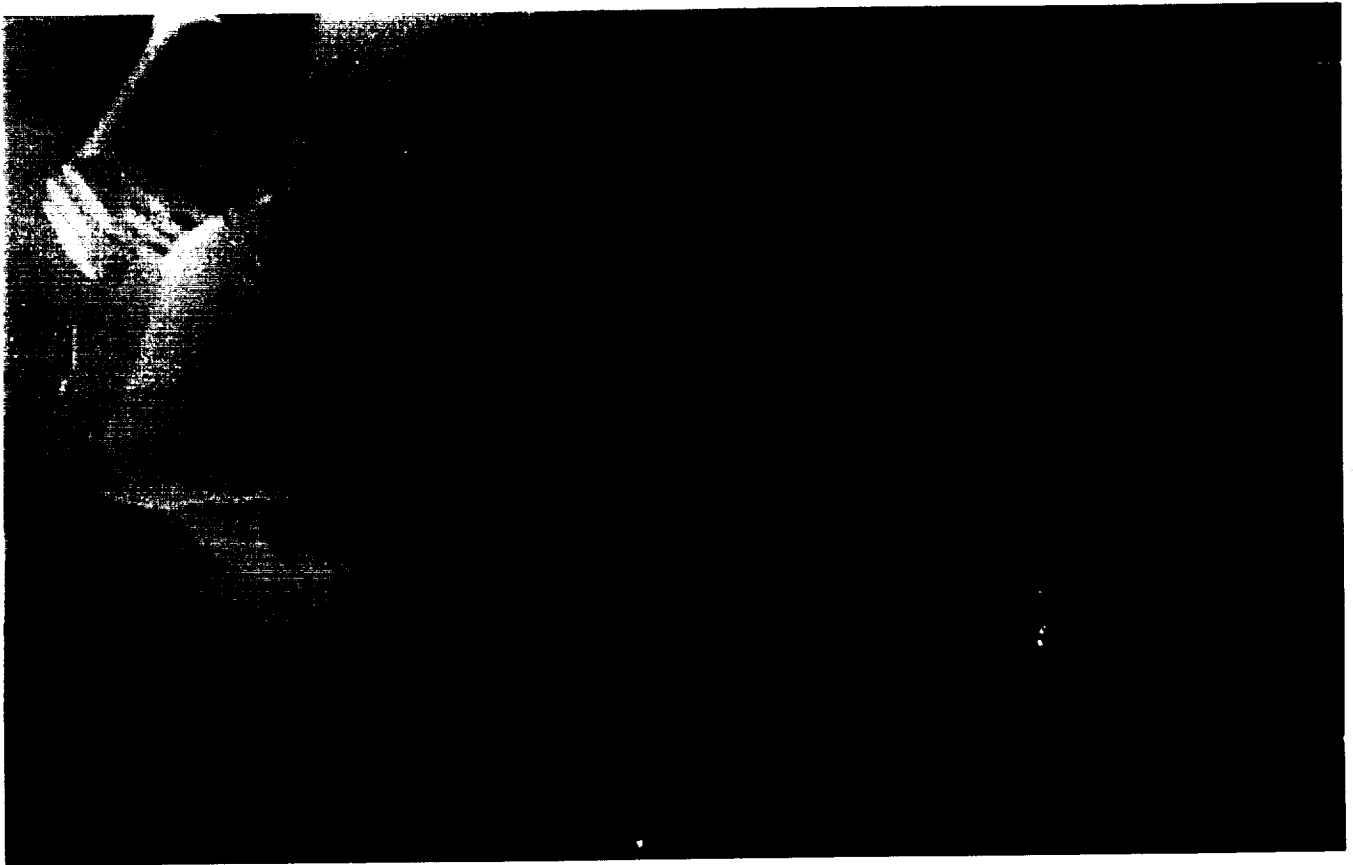


Photo 10: SRB Stud Hang-ups

For only the second time, two stud hang-ups occurred (the data base showed STS-2, holddown posts #6 and #8). The STS-92 hang-ups occurred on HDP #2 and #4. The pattern was similar for both posts - the stud was held fully extended until the aft skirt foot was clear. Then the stud twanged briefly before falling into the holddown post. A piece of shaved aluminum from the bore fell with the stud (arrows).

6.2 ON-ORBIT FILM AND VIDEO SUMMARY

As expected, no Solid Rocket Booster or External Tank separation photography was acquired on STS-92. The 35mm film from the LO2 ET/ORB umbilical was unusable due to the night time conditions at ET separation. No attempt was made by the crew to take handheld 35mm stills or camcorder video of the ET because of the dark conditions. The two 16mm cameras in the LO2 ET/ORB umbilical were disabled prior to launch because of an electrical short problem.

6.3 LANDING FILM AND VIDEO SUMMARY

A total of 17 films and videos, which included eight 35mm large format films and nine videos, were reviewed.

The landing gear extended properly. The right MLG tires contacted the runway first.

Drag chute deployment appeared normal. No anomalies were detected from touchdown through rollout. No unusual tile damage was visible in the films.

7.0 SRB POST FLIGHT/RETRIEVAL DEBRIS ASSESSMENT

The BI-104 Solid Rocket Boosters were inspected for debris damage and debris sources at CCAFS Hangar AF on 16 October 2000. Generally, both boosters were in excellent condition.

As expected, broaching occurred in the holddown stud bores of posts #2 and #4 consistent with stud hang-ups seen in the post launch film reviews. Both broached areas were generally on the +Z side of the bore, though only #2 had stud thread impressions as well. The DCS #2 plunger was obstructed by a frangible nut piece while the #4 plunger was seated. Upon further review, the database showed only the STS-2 mission (posts #6 and #8) as having multiple stud hang-ups. The holddown post Debris Containment Systems (DCS) not affected by the stud hang-ups appeared to have functioned normally.

A 2.5-inch long (circumferential) by 1-inch deep crack in the cork closeout was detected in the RH center field joint leading edge at approximately 220 degrees. Sooting was visible adjacent to the crack as well as inside the crack to a point about half the depth. Although some of the Hypalon paint was missing at this location, no obvious signs of impact by debris objects were noted. This was the third occurrence in RSRM history (STS-61, -94, and -92) with all cracks on the RH center field joint closeout between 200-220 degrees. Post flight testing of cork impacts along with debris trajectory analysis concluded the cracks were caused by impacts from pieces of External Tank LO2 feedline upper bellows ice. The other Field Joint Protection System (FJPS) and the System Tunnel Covers closeouts were generally in good condition with no unbonds observed.

The TPS on both frustums exhibited no debonds/unbonds. There was one small area of blistered Hypalon on the -Z side of the right frustum.

All eight BSM aero heat shield covers had fully opened and locked.

A pin, retaining clip, and small piece of adjacent insulation were missing from the RSRB forward skirt severance ring at approximately 138 degrees. Parachute riser entanglement most likely caused this.

The forward skirts exhibited no debonds or missing TPS. RSS antennae covers/phenolic base plates were intact, though one layer of the RSRB +Z antenna base plate had delaminated.

Separation of the aft ET/SRB struts appeared normal.

Aft skirt external surface TPS was in good condition. Typical blistering of Hypalon paint had occurred on the BTA insulation close-outs.

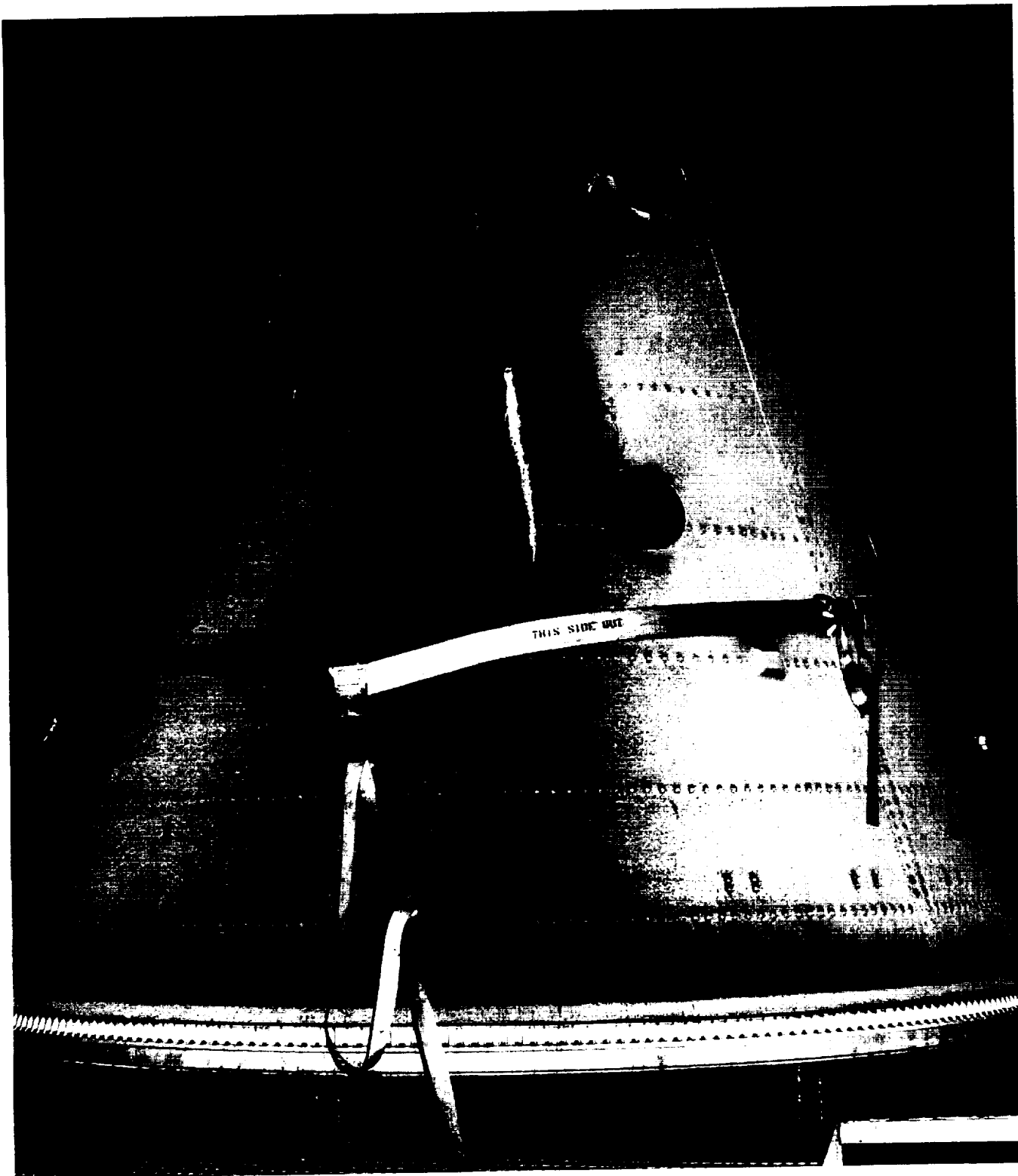


Photo 11: Frustum Post Flight Condition

The frustums exhibited no debonds/unbonds or missing TPS.
All eight BSM aero heat shield covers had locked in the fully opened position.

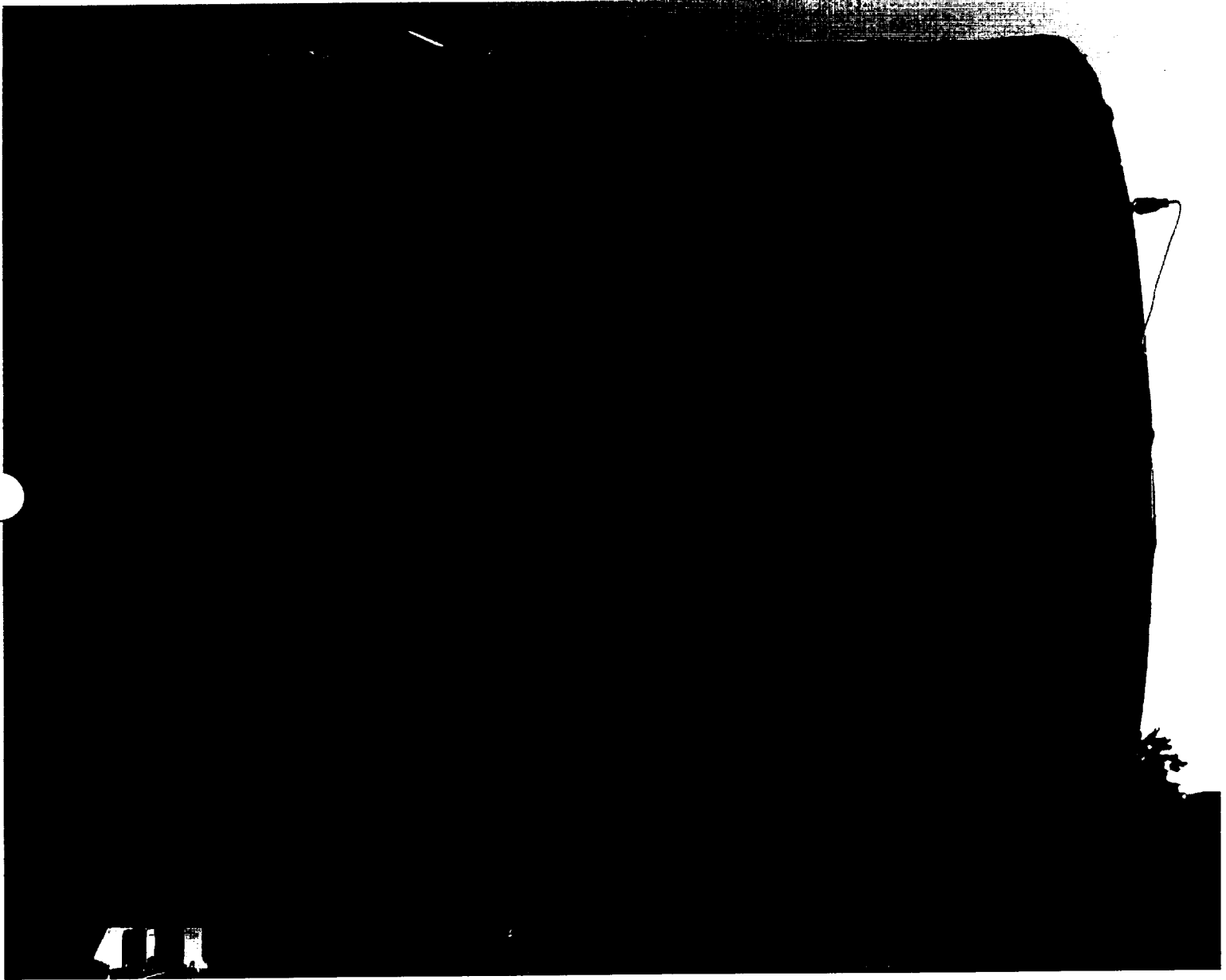


Photo 12: Forward Skirt Post Flight Condition

The forward skirts exhibited no debonds or missing TPS. RSS antennae covers/phenolic base plates were intact, though one layer of the RSRB +Z antenna base plate had delaminated.

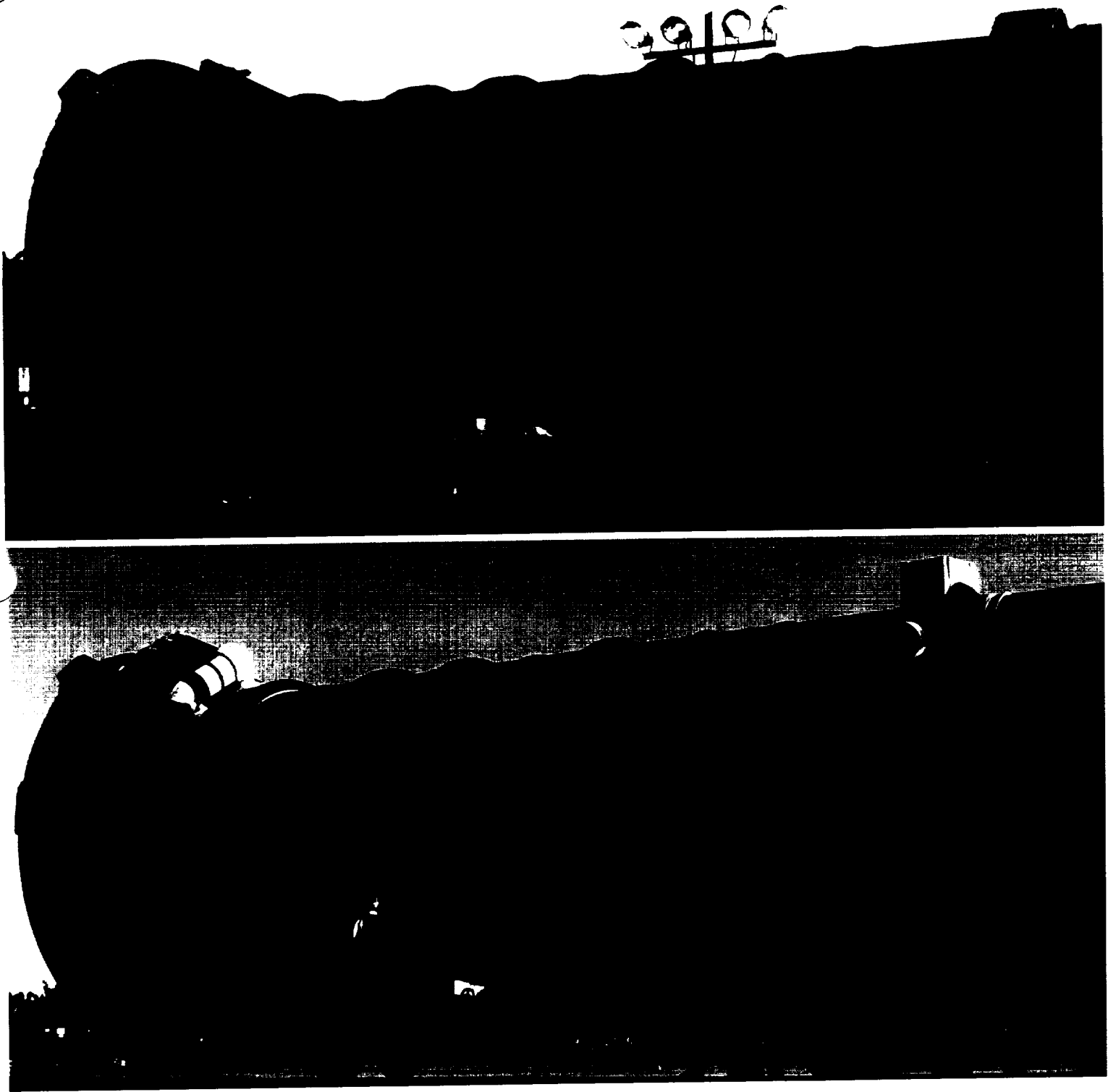


Photo 13: Aft Skirt Post Flight Condition
Aft skirt external surface TPS was in good condition



Photo 14: Broaching Due to Stud Hang-ups

Broaching occurred in the holddown stud bores of posts #2 and #4 consistent with stud hang-ups seen in the post launch film reviews. Both broached areas were generally on the +Z side of the bore, though only #2 had stud thread impressions as well. The DCS #2 plunger was obstructed by a frangible nut piece while the #4 plunger was seated. Upon further review, the database showed only the STS-2 mission (posts #6 and #8) as having multiple stud hang-ups.

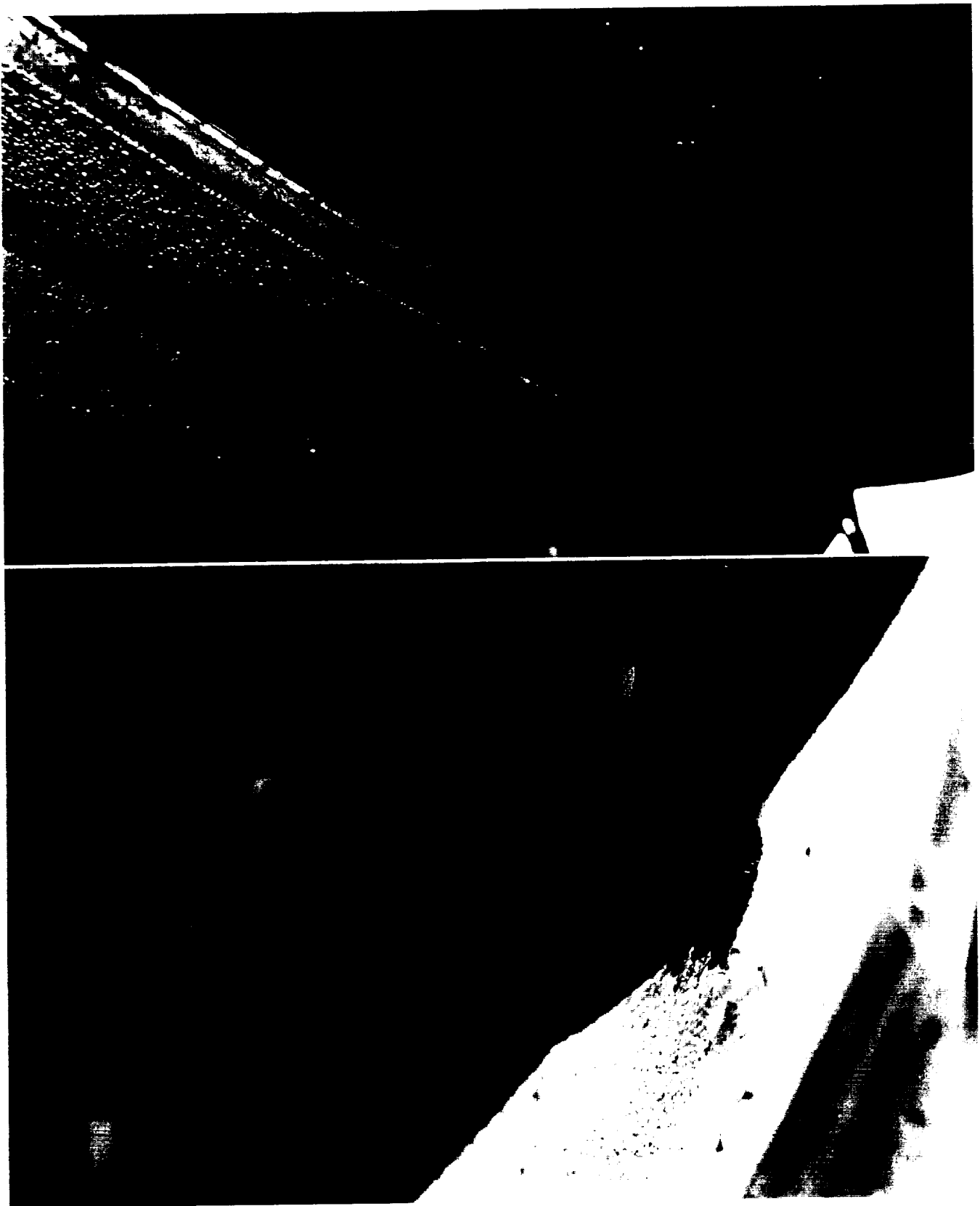


Photo 15: Crack in Cork Closeout

A 2.5-inch long by 1-inch deep crack in the cork closeout was detected in the RH center field joint leading edge at approximately 220 degrees. Sooting was visible adjacent to the crack as well as inside the crack to a point about half the depth. Post flight testing of cork impacts along with debris trajectory analysis concluded the cracks were caused by impacts from pieces of External Tank LO2 feedline upper bellows ice.

8.0 ORBITER POST LANDING DEBRIS ASSESSMENT

After the 1:59 pm local/pacific time landing on 24 October 2000, a post landing inspection of OV-103 Discovery was conducted on Edwards Air Force Base Runway 22. The final inspection was performed at the Mate Demate Device (MDD) on 25 October 2000. This inspection was performed to identify debris impact damage and, if possible, debris sources.

The Orbiter TPS sustained a total of 127 hits, of which 24 had a major dimension of 1-inch or larger. This total does not include the numerous hits on the base heat shield attributed to SSME vibration/acoustics and exhaust plume recirculation (reference Figures 1-4).

The following table lists the STS-92 Orbiter damage hits by area:

| | <u>HITS > 1-inch</u> | <u>TOTAL HITS</u> |
|---------------|-------------------------|-------------------|
| Lower Surface | 14 | 86 |
| Upper Surface | 1 | 7 |
| Window Area | 6 | 16 |
| Right Side | 0 | 0 |
| Left Side | 0 | 0 |
| Right OMS Pod | 3 | 11 |
| Left OMS Pod | 0 | 7 |
| TOTALS | 24 | 127 |

The Orbiter lower surface sustained 86 total hits, of which 14 had a major dimension of 1-inch or larger. Approximately 33 damage sites (with three larger than 1-inch in length) were located in the area from the nose gear to the main landing gear wheel wells. The majority of this damage occurred on the right-hand side of the vehicle, though some of these hits may be attributed to impacts from ice in the LO2 feedline bellows. ET TPS venting modifications continue to have a reducing effect on the quantity and size of the damage sites.

The largest lower surface tile damage site, located on the right wing just outboard of the LO2 umbilical door, measured 2-inches long by 1-inch wide by 0.75-inches deep. The cause of this damage site is believed to be ice from the ET LO2 feedline.

Numerous tile damage sites around the LH2 ET/ORB umbilical were most likely caused by pieces of the umbilical purge barrier flailing in the airstream and contacting tiles before pulling loose and falling aft.

The landing gear tires were reported to be in good condition. There was no ply under cutting on the main landing gear tires.

No debris was found beneath the ET/ORB umbilicals. The EO-2 and EO-3 salad bowls appeared to be in normal condition. However, the LH2 side had a 2-inch by 3-inch piece of purge barrier adhering to the bowl. All the EO fittings appeared to have functioned normally.

Less than usual amounts of tile damage occurred on the base heat shield. SSME #1 Dome Heat Shield closeout blankets were slightly frayed at the six-o'clock position. The SSME #2 blanket was frayed between the 1:00 to 3:00 o'clock positions.

No unusual tile damage occurred on the leading edges of the OMS pods. Eleven hits were noted on the leading edge of the right OMS pod (with three having a dimension larger than 1-inch). The left OMS pod had seven hits, none greater than 1-inch.

Several vertical stabilizer leading edge tile damage sites were observed with one appearing to have a major dimension of approximately four inches. Post flight debris trajectory analysis by Boeing-Huntington Beach concluded that pieces of ET foam did not have enough density to crack the tiles. The damage was more than likely caused by the FRCS paper covers with higher density RTV adhesive.

Damage sites on the window perimeter tiles appeared to be less than usual in quantity and size, with the exception of window #5, which sustained eight hits on the perimeter tiles. Hazing and streaking of forward-facing Orbiter windows was moderate. Window #5 had a small impact site on the lower aft portion, which may have been caused by an orbital debris impact.

Approximately five cracks in the FRSI were noted on top of the crew cabin and on the left forward payload bay door ranging from 3-feet to 5-feet in length. Although not considered to be a result of debris impacts, the cracks were larger than previously observed.

A post landing walk-down of the runway was performed. No flight hardware was found. Recovered debris, which included an orange rubber electrical D-connector 1/2-inch long by 1/16-inch thick found in the vicinity of the drogue chute, and a 0.375-inch diameter by 0.1-inch long bushing found on the ground underneath the nose gear doors, did not originate from the Orbiter. All components of the drag chute were recovered and appeared to have functioned normally.

In summary, both the total number of Orbiter TPS debris hits and the number of hits 1-inch or larger were somewhat greater than the fleet averages (reference Figure 5).

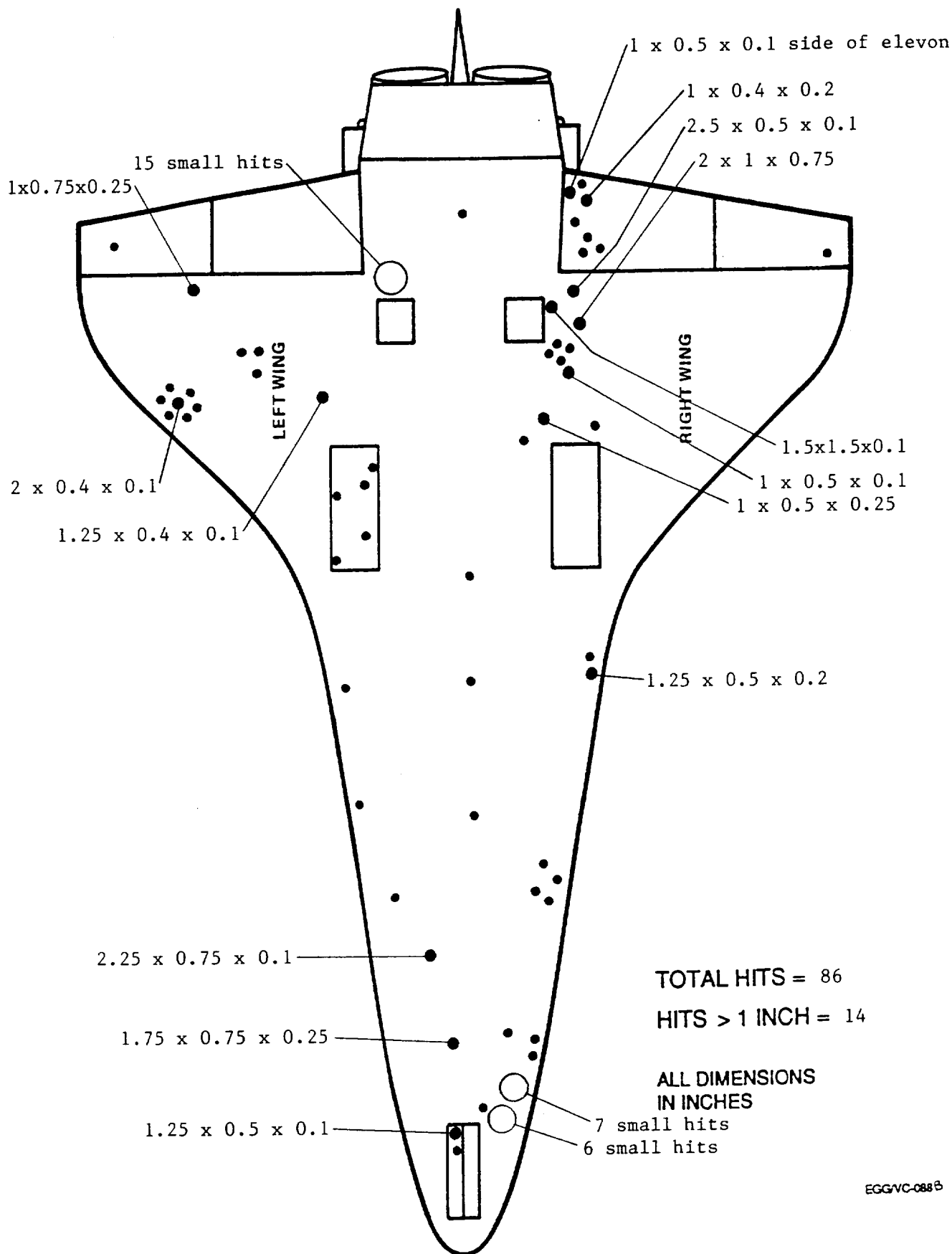
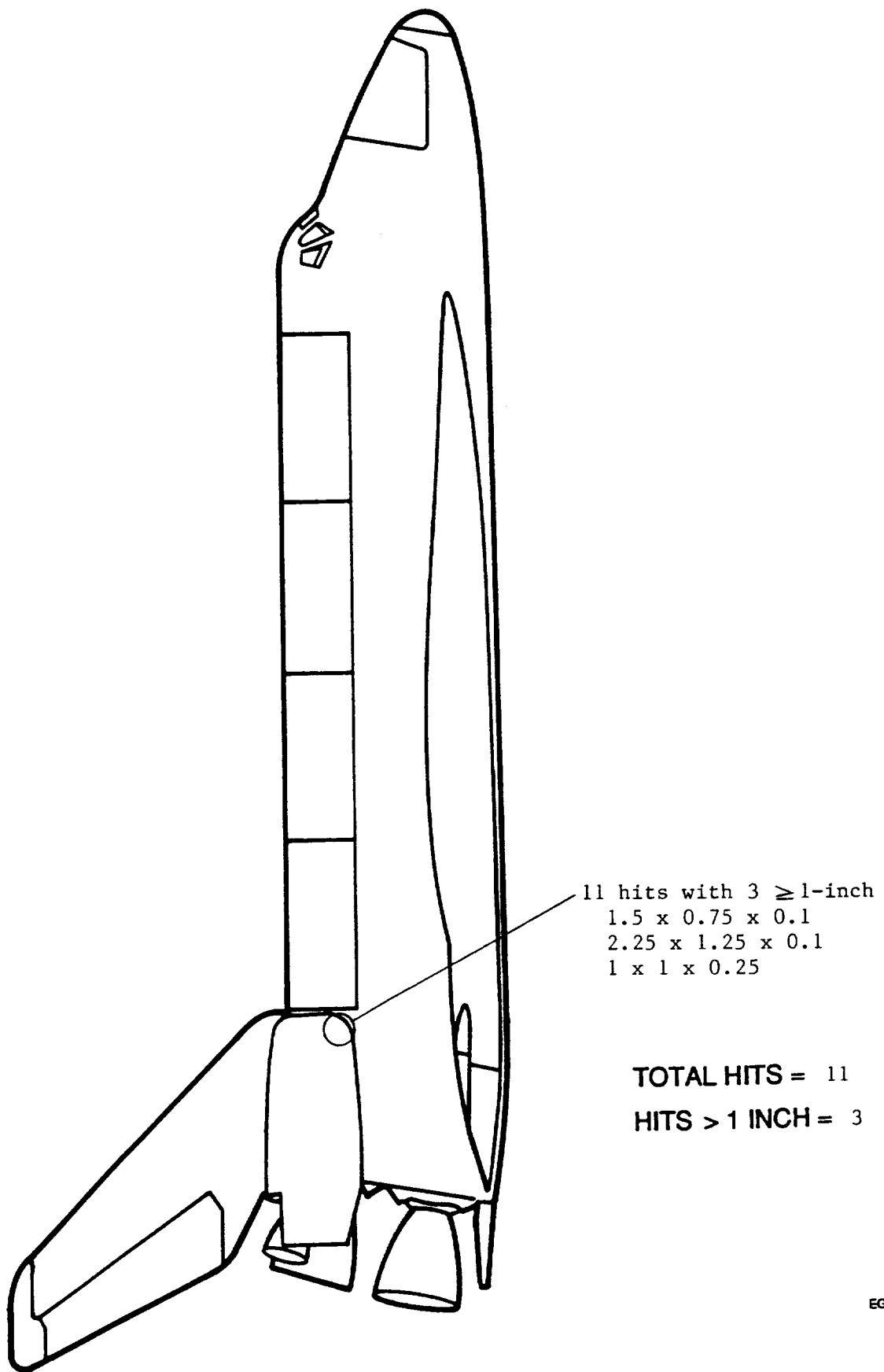


Figure 1: Orbiter Lower Surface Debris Damage Map



EGGVC-088A

Figure 2: Orbiter Right Side Debris Damage Map

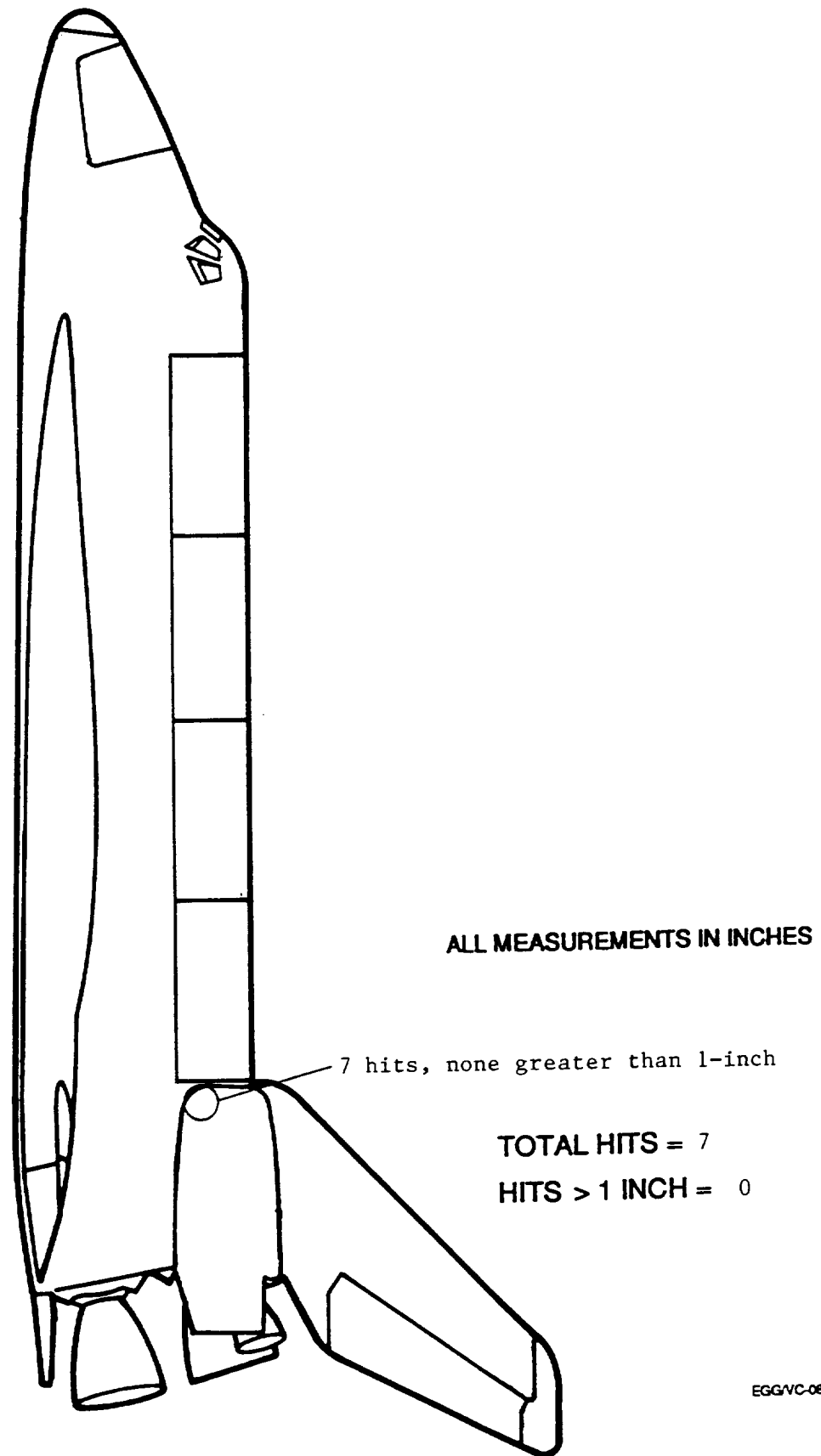


Figure 3: Orbiter Left Side Debris Damage Map

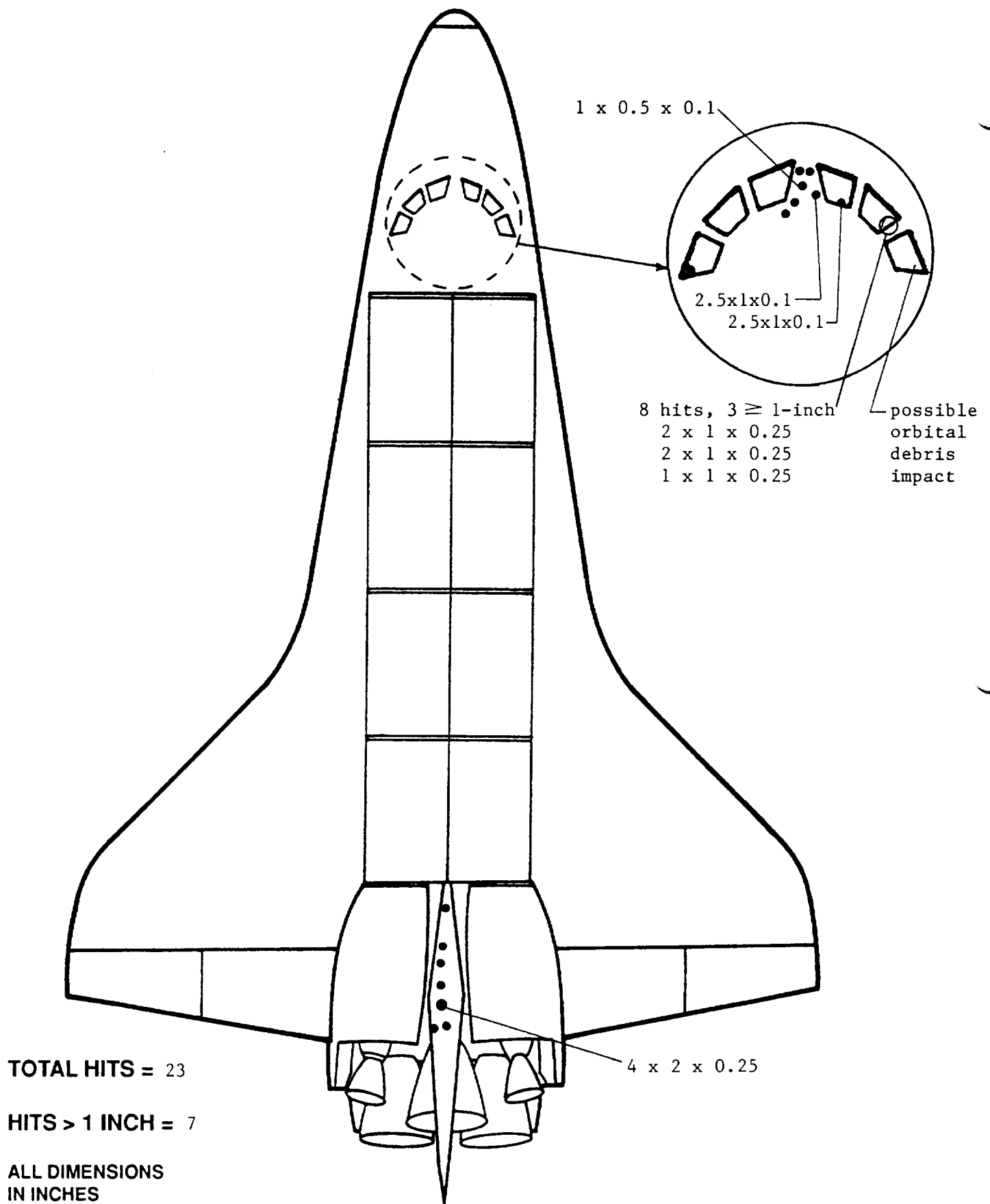


Figure 4: Orbiter Upper Surface Debris Damage Map

| STS NUMBER | LOWER SURFACE | | ENTIRE SURFACE | |
|------------|---------------|------------|----------------|------------|
| | HITS > 1 INCH | TOTAL HITS | HITS > 1 INCH | TOTAL HITS |
| STS-70 | 5 | 81 | 9 | 127 |
| STS-69 | 22 | 175 | 27 | 198 |
| STS-73 | 17 | 102 | 26 | 147 |
| STS-74 | 17 | 78 | 21 | 116 |
| STS-72 | 3 | 23 | 6 | 55 |
| STS-75 | 11 | 55 | 17 | 96 |
| STS-76 | 5 | 32 | 15 | 69 |
| STS-77 | 15 | 48 | 17 | 81 |
| STS-78 | 5 | 35 | 12 | 85 |
| STS-79 | 8 | 65 | 11 | 103 |
| STS-80 | 4 | 34 | 8 | 93 |
| STS-81 | 14 | 48 | 15 | 100 |
| STS-82 | 14 | 53 | 18 | 103 |
| STS-83 | 7 | 38 | 13 | 81 |
| STS-84 | 10 | 67 | 13 | 103 |
| STS-94 | 11 | 34 | 12 | 90 |
| STS-85 | 6 | 37 | 13 | 102 |
| STS-99 | 21 | 75 | 25 | 88 |
| STS-101 | 19 | 70 | 27 | 113 |
| STS-106 | 17 | 73 | 17 | 105 |
| | | | | |
| AVERAGE | 11.6 | 61.2 | 16.1 | 102.8 |
| SIGMA | 6.0 | 33.9 | 6.3 | 30.0 |
| | | | | |
| STS-92 | 14 | 86 | 24 | 127 |
| | | | | |

MISSIONS STS-86,87,89,90,91,95,88,96,93,103 ARE NOT INCLUDED SINCE THESE MISSIONS HAD SIGNIFICANT DAMAGE CAUSED BY KNOWN DEBRIS SOURCES

Figure 5: Orbiter Post Flight Debris Damage Summary

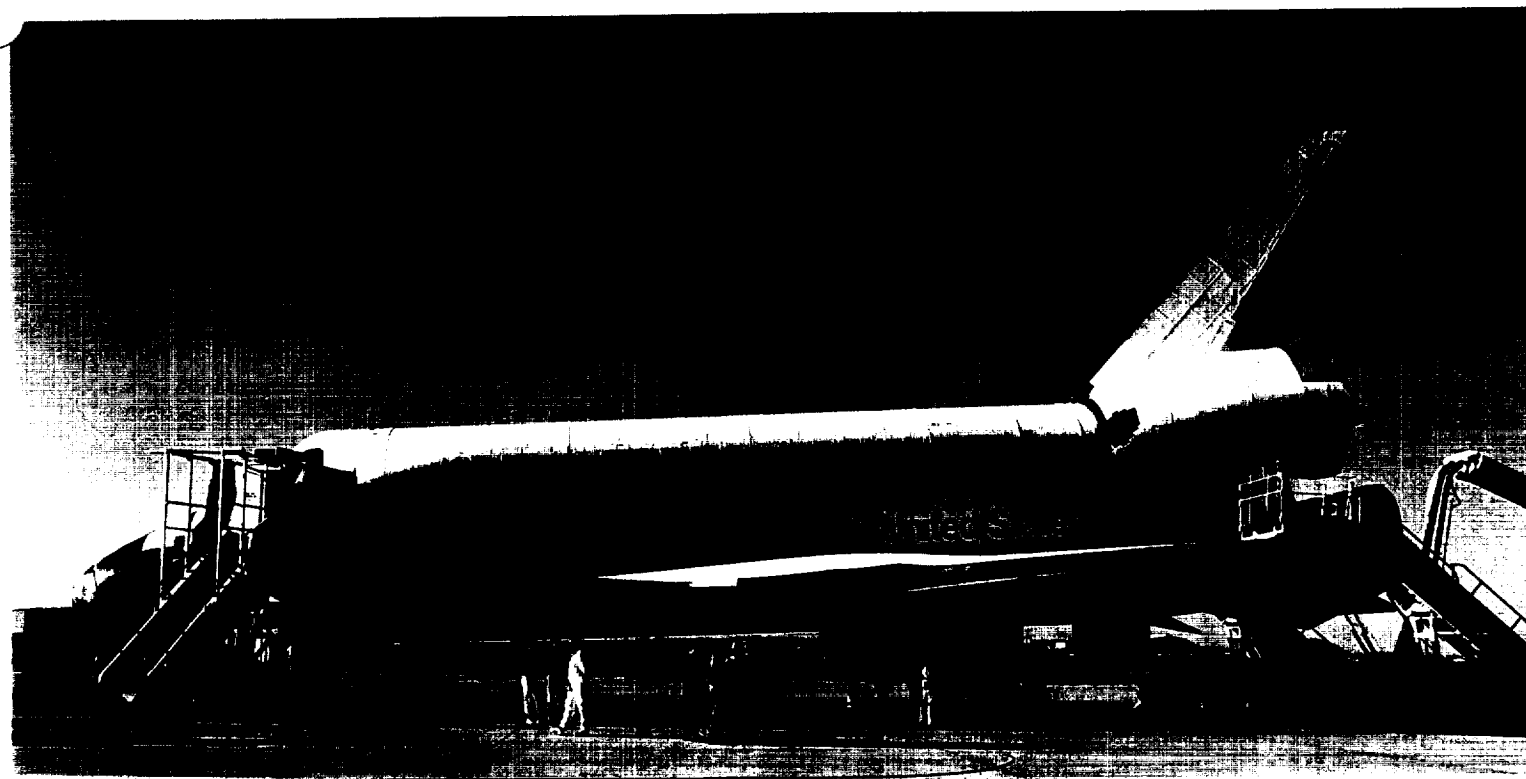
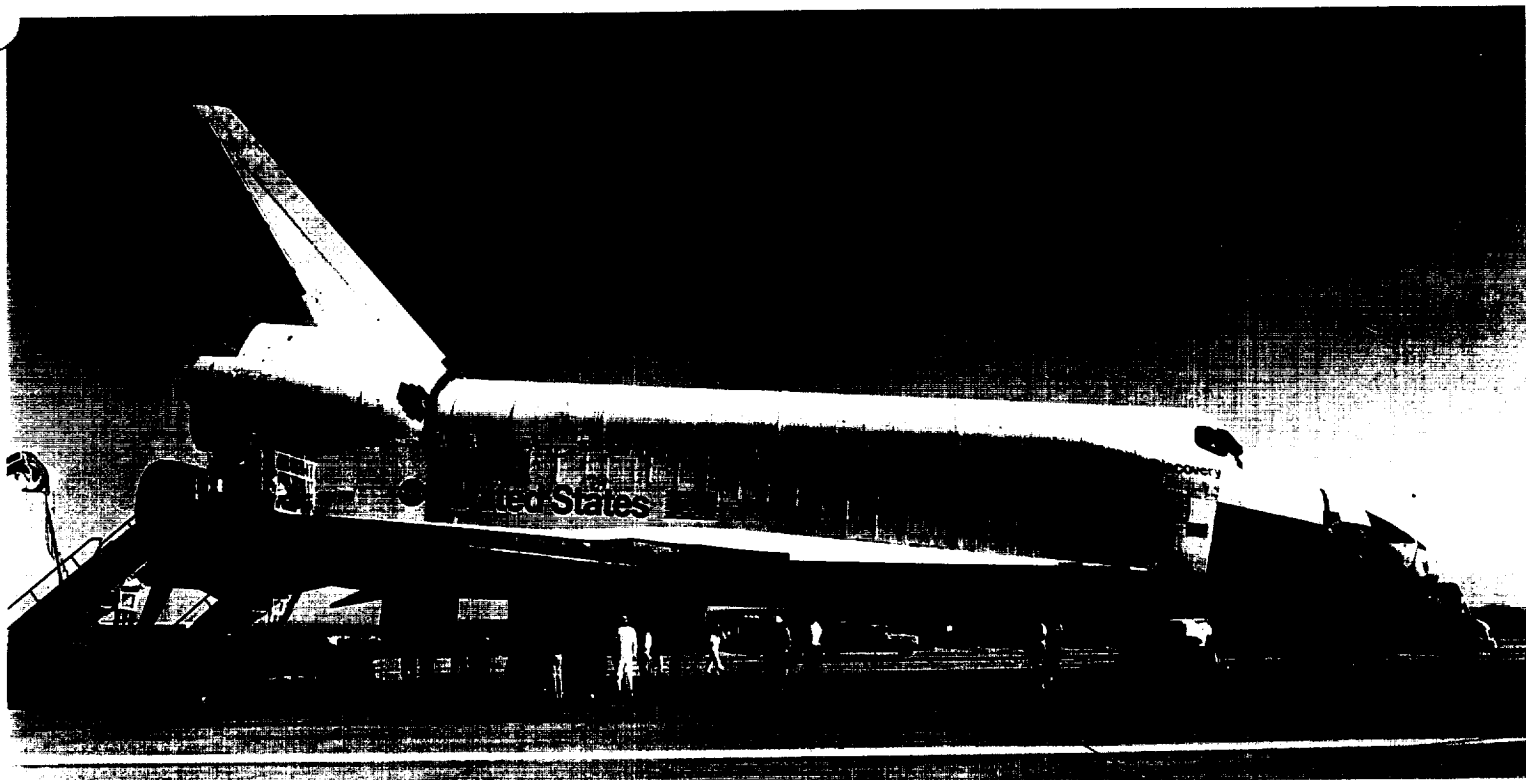


Photo 16: Overall View of Orbiter Sides

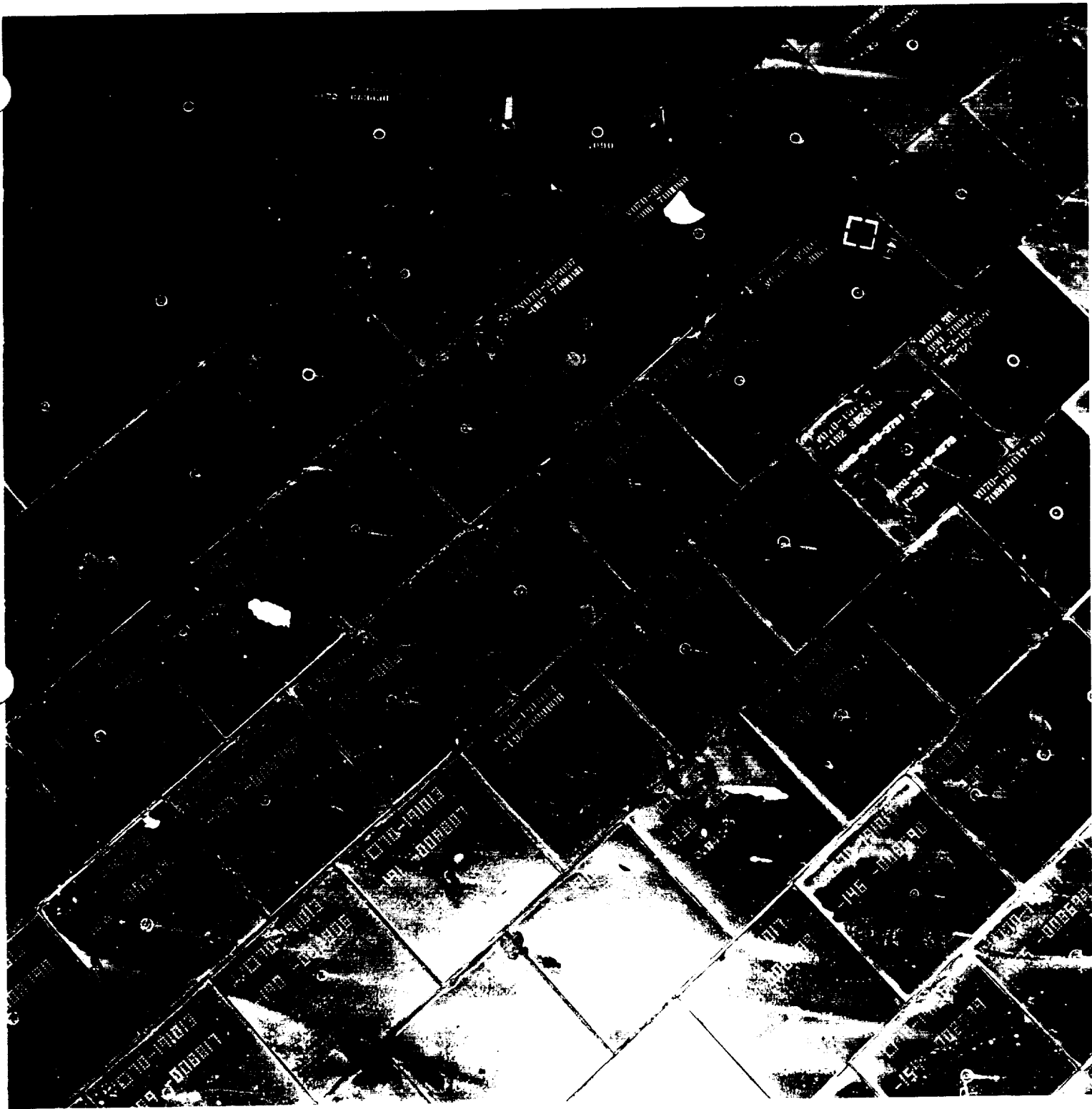


Photo 17: Damage to Lower Surface Tiles

The Orbiter lower surface sustained 86 total hits, of which 14 had a major dimension of 1-inch or larger. Approximately 33 damage sites (with three larger than 1-inch in length) were located in the area from the nose gear to the main landing gear wheel wells. The majority of this damage occurred on the right-hand side of the vehicle, though some of these hits may be attributed to impacts from ice in the LO2 feedline bellows. ET TPS venting modifications continue to have a reducing effect on the quantity and size of the damage sites.

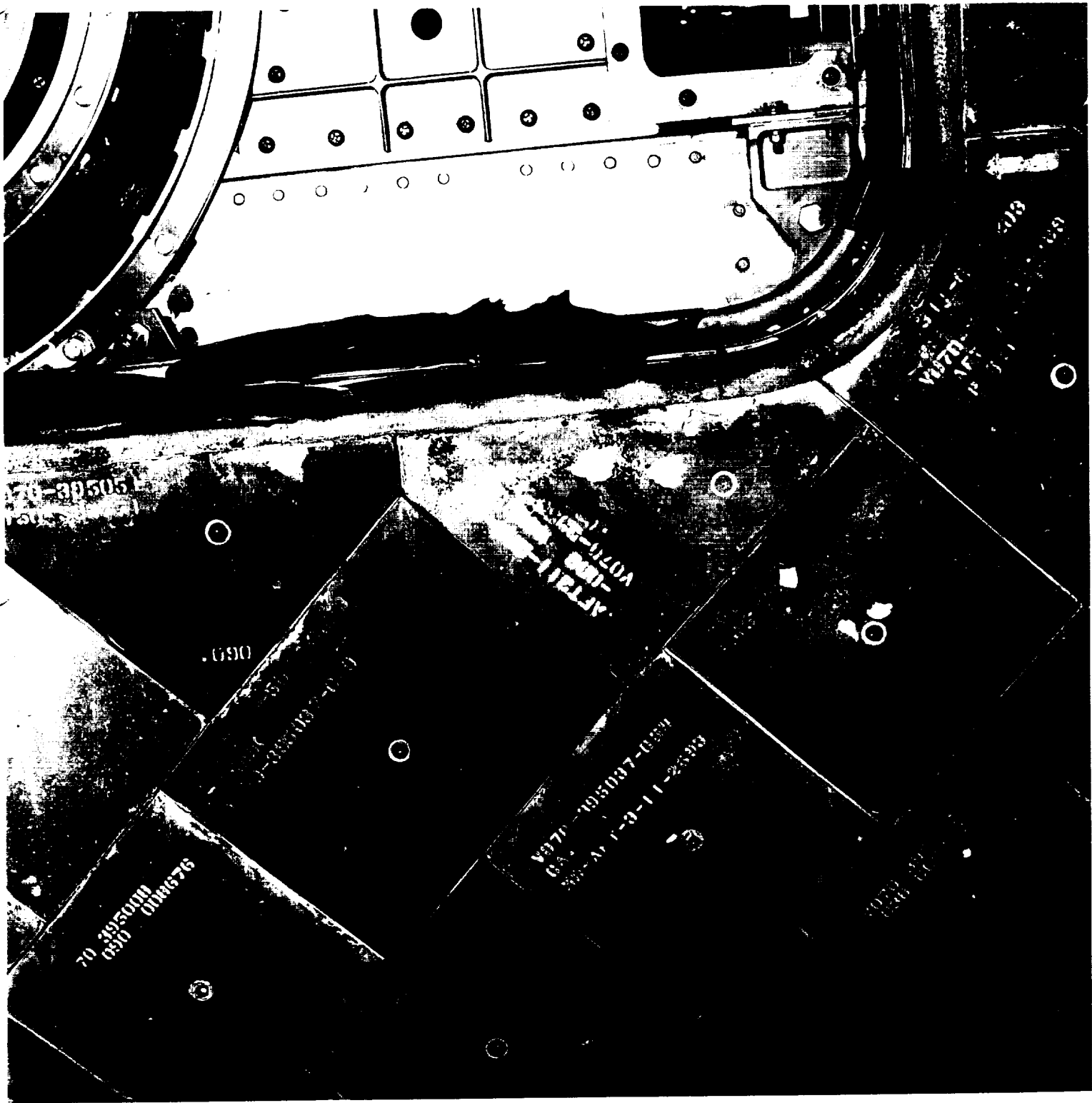


Photo 18: Tile Damage Near Umbilicals

Numerous tile damage sites around the LH2 ET/ORB umbilical were most likely caused by pieces of the umbilical purge barrier flailing in the airstream and contacting tiles before pulling loose and falling aft.



Photo 19: Hairline Cracks in Thermal Blankets

Approximately five cracks in the FRSI were noted on top of the crew cabin and on the left forward payload bay door ranging from 3-feet to 5-feet in length. Although not considered to be a result of debris impacts, the cracks were larger than previously observed.

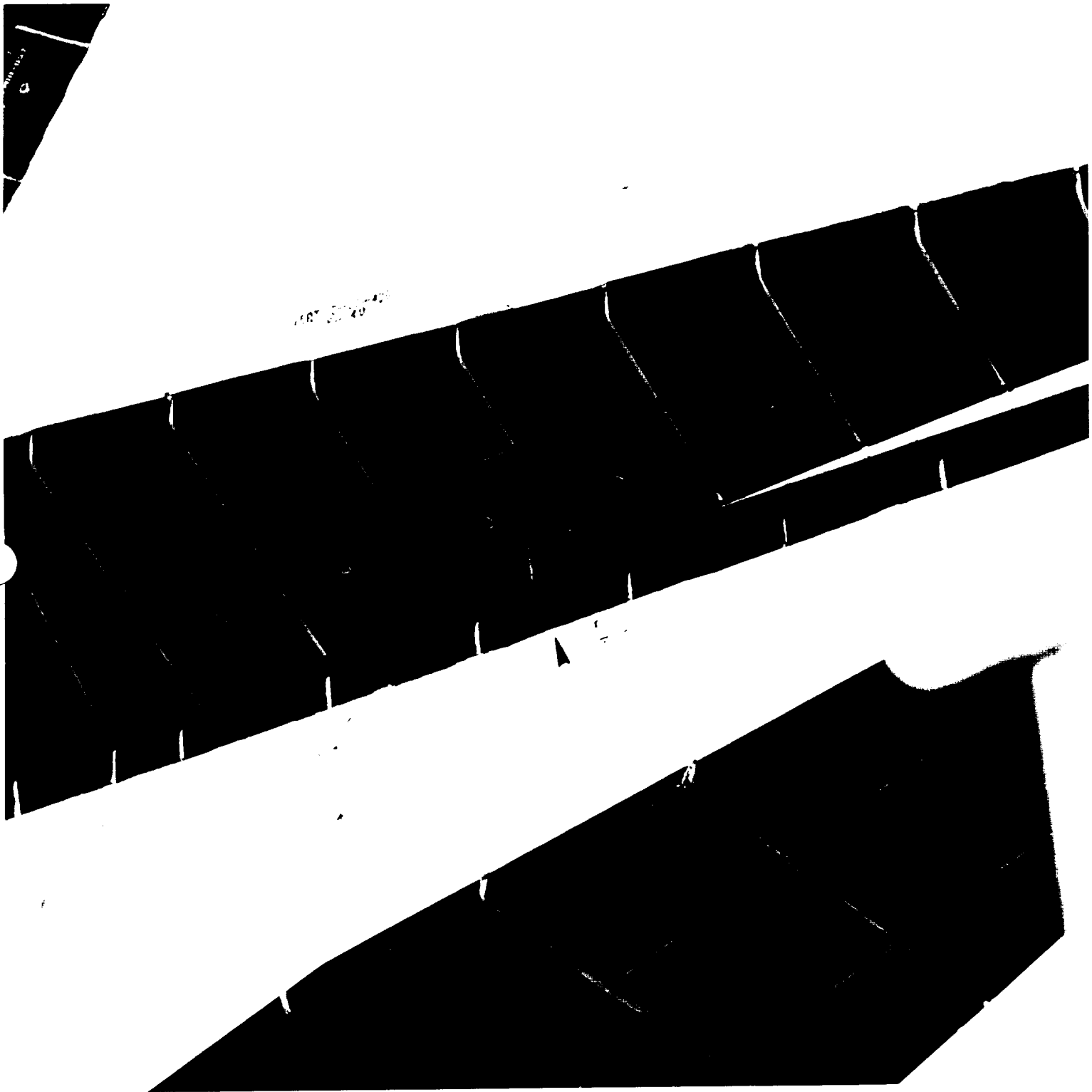


Photo 20: Rudder/Speed Brake Spring Clip

A piece of the rudder/spring brake spring clip was imbedded in stinger tiles

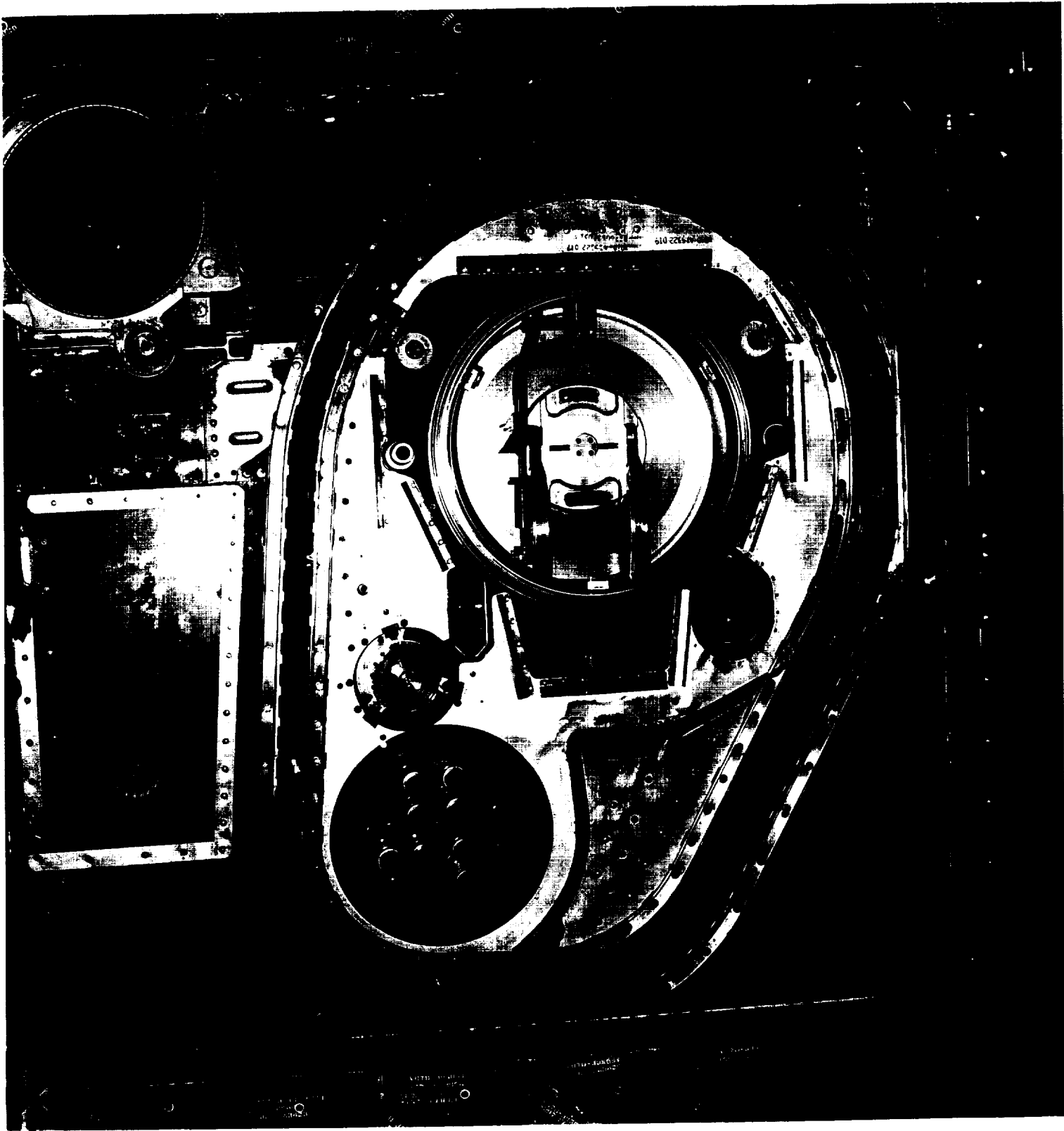


Photo 21: LO2 ET/ORB Umbilical

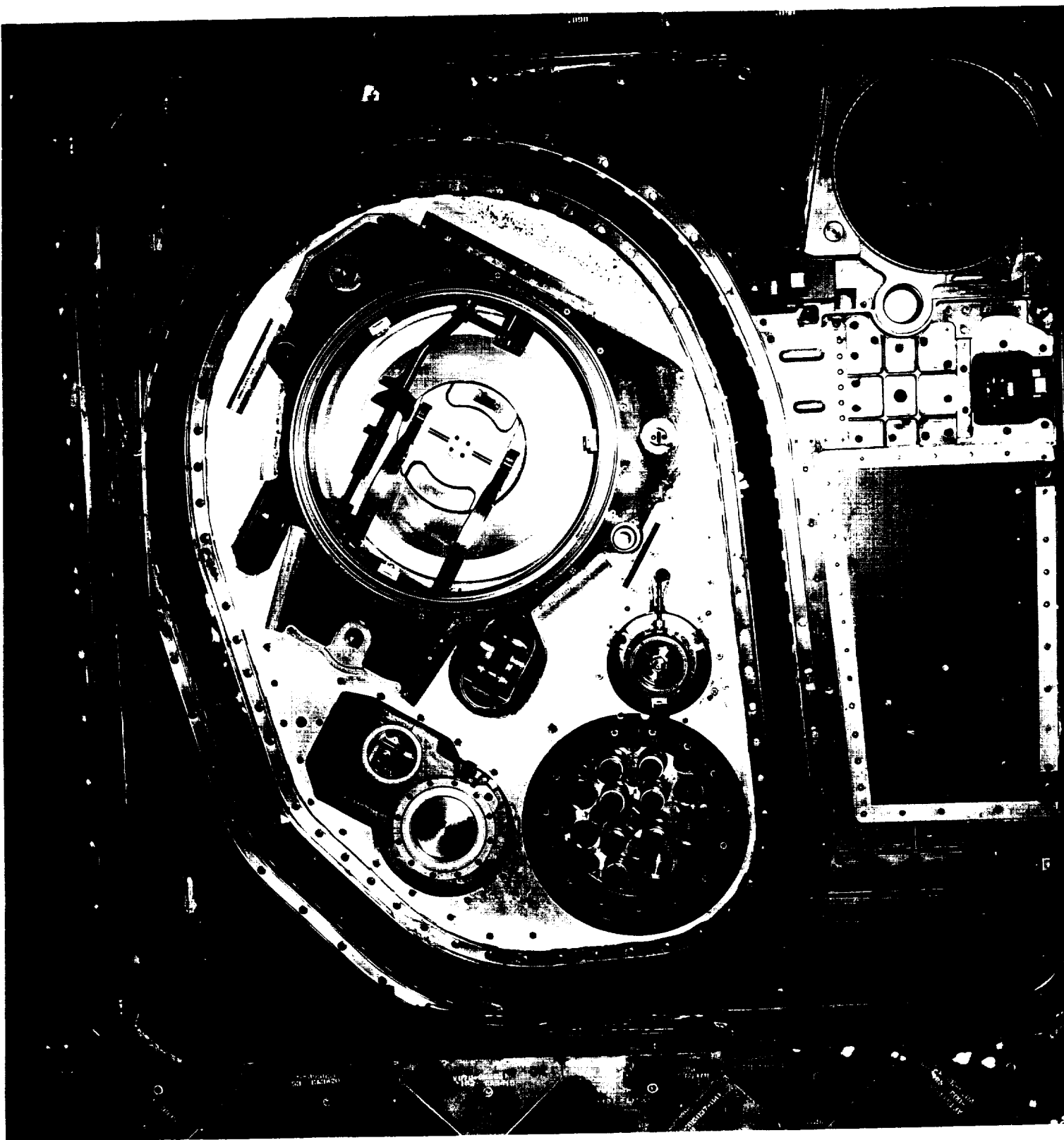


Photo 22: LH2 ET/ORB Umbilical



Photo 23: Windows

Damage sites on the window perimeter tiles appeared to be less than usual in quantity and size, with the exception of window #5, which sustained eight hits on the perimeter tiles. Hazing and streaking of forward-facing Orbiter windows was moderate. Window #5 had a small impact site on the lower aft portion, which may have been caused by an orbital debris impact.

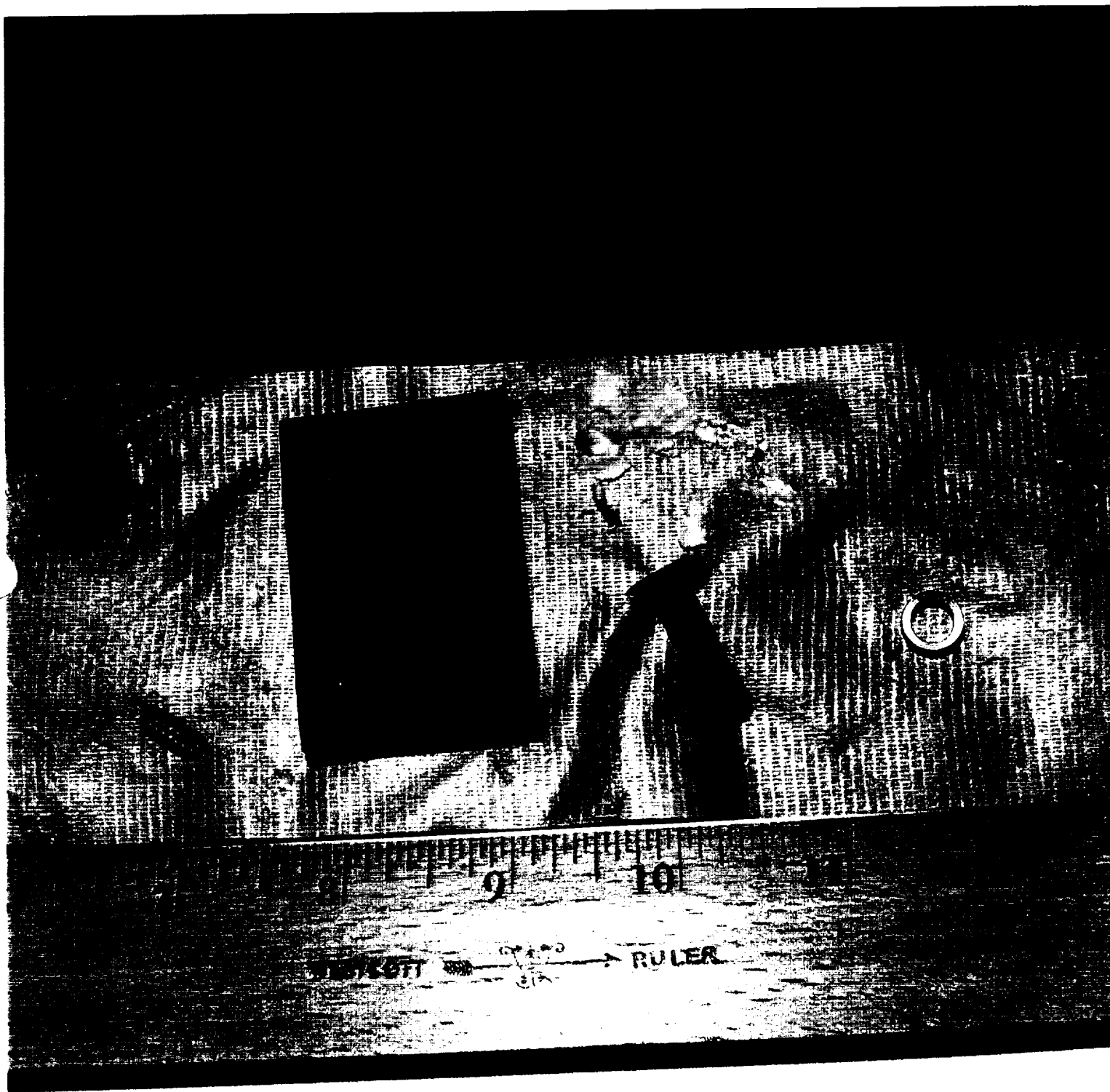


Photo 24: Debris Found on Runway

None of the debris found on the runway originated from the Orbiter

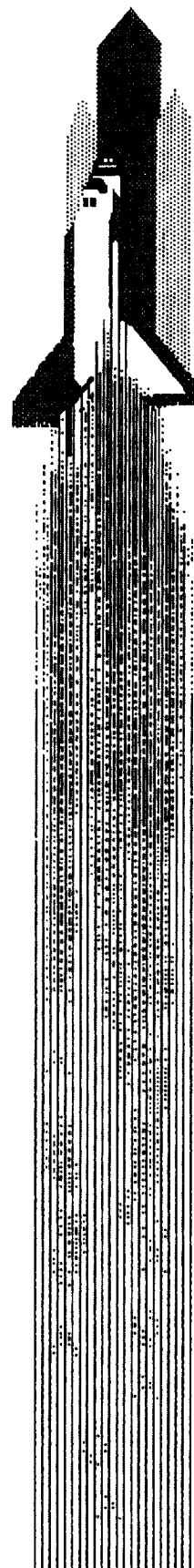
APPENDIX A. JSC PHOTOGRAPHIC ANALYSIS SUMMARY



Space Science Branch

STS-92 Summary of Significant Events

December 11, 2000





Space Shuttle

STS-92 Summary of Significant Events

Project Work Order - SN3CSE

Approved By

Lockheed Martin

Jon Disler, Project Analyst
Image Science and Analysis Group

NASA

Greg Byrne, Lead
Image Science and Analysis Group
Space Science Branch

Michael Snyder, Project Manager
Image Analysis Projects

Robert W. Payne, Department Manager
Basic and Applied Research Department

Prepared By

Lockheed Martin Engineering and Sciences Company
for
Space Science Branch
Earth Sciences and Solar System Exploration Division
Space and Life Sciences Directorate

Table of Contents

| | | |
|-----------|---|-----------|
| 1. | STS-92 (OV-103): FILM/VIDEO SCREENING AND TIMING SUMMARY | A5 |
| 1.1 | Screening Activities | A5 |
| 1.1.1 | Launch | A5 |
| 1.1.2 | On-Orbit..... | A5 |
| 1.1.3 | Landing | A5 |
| 1.2 | Landing Events Timing..... | A6 |
| 2. | SUMMARY OF SIGNIFICANT EVENTS | A8 |
| 2.1 | Debris from SSME Ignition through Liftoff | A8 |
| 2.2 | Debris During Ascent | A10 |
| 2.3 | Mobile Launch Platform (MLP) Events | A12 |
| 2.3.1 | Anomaly - RSRB Holddown Posts M-2 and M-4 Bolt Hang-ups..... | A12 |
| 2.3.2 | Mobile Launch Pad Observations | A13 |
| 2.4 | Ascent Events..... | A15 |
| 2.5 | ONBOARD PHOTOGRAPHY OF THE EXTERNAL TANK (ET-104)..... | A17 |
| 2.6 | LANDING SINK RATE ANALYSIS | A17 |
| 2.7 | OTHER | A19 |
| 2.7.1 | Normal Events | A19 |
| 2.7.2 | Normal Pad Events | A19 |

Tables and Figures

| | | |
|----------------|--|-----|
| Table 1.2 | Landing Event Times | A7 |
| Figure 2.1 (A) | Umbilical Ice Debris Contacting LH2 Electric Cable Tray..... | A8 |
| Figure 2.1 (B) | Debris from RSRB Flame Duct at Liftoff..... | A9 |
| Figure 2.2 | Debris Exiting RSRB Exhaust Plume (ET213)..... | A11 |
| Figure 2.3.1 | RSRB Holddown Posts M-2 and M-4 Bolt Hang-ups | A12 |
| Figure 2.3.2 | Orange Vapor Forward of SSME Rims..... | A13 |
| Table 2.3 | SSME Mach Diamond Formation Times | A14 |
| Figure 2.4 (A) | Vapors Aft of ET Aft Dome | A15 |
| Figure 2.4 (B) | Flares in the SSME Exhaust Plume (Camera E222) | A16 |
| Table 2.6 | Main Gear Landing Sink Rate | A18 |
| Figure 2.6 (A) | Main Gear Landing Sink Rate | A18 |

STS-92 (OV-103) Film/Video Screening and Timing Summary

1. STS-92 (OV-103): FILM/VIDEO SCREENING AND TIMING SUMMARY

1.1 SCREENING ACTIVITIES

1.1.1 Launch

The STS-92 launch of Discovery (OV-103) from Pad 39A occurred on Wednesday, October 11, 2000 at approximately 285:23:17:00.022 UTC as seen on camera E13. SRB separation occurred at approximately 23:19:03.0 UTC as seen on camera ET212A.

On launch day, 22 of the 24 expected videos were received and screened (OTV041 and OTV048 were not received). Clouds intermittently obscured the long-range tracking views of the launch vehicle during ascent.

Twenty-three launch films were screened and a report was sent to the Shuttle Program distribution on October 14, 2000. Seventeen additional films were received for contingency support and anomaly resolution.

One anomalous event was seen during the review of the STS-92 launch films. SRB holddown post stud hang-ups were seen at the RSRB holddown posts M-2 and M-4 at liftoff. Both of the holddown post studs appeared fully extended before they released and fell back into the holddown posts.

No External Tank or SRB separation photography was acquired on STS-92. (See Section 2.5)

Video (acquired from cameras mounted on the SRB forward skirts) of the External Tank's +Y and -Y thrust panels was not acquired during ascent on STS-92.

1.1.2 On-Orbit

No unplanned on-orbit Shuttle support tasks were requested on STS-92.

Pre-planned real-time analysis support was provided to the ISS AF-3A Space Station photographic and television external survey. The Space Station image analysis support will be documented in the AF-3A Imagery Overview Report.

1.1.3 Landing

For the first time since March 1996, the Orbiter (OV-103) made a daytime landing at Edwards Air Force Base (EAFB). Discovery landed on EAFB runway 22 on October 24, 2000 at 20:59:22.8 UTC. Four public affairs landing videos and the Heads Up Display (HUD) videos were received. The expected engineering video replays with actual landing times were not received. The NASA select live video with correct landing times was used for the landing event times (see Section 1.2, Table 1.2). Five 16mm landing films were received twelve days after landing.

STS-92 (OV-103) Film/Video Screening and Timing Summary

Three 35mm color reversal films had to be returned to EAFB for processing. These three films plus one additional 16mm film were not received in time to be used for the landing sink rate analysis. The long range Contraves tracking films were not received.

The landing touchdown appeared normal. No anomalous events were seen during the Orbiter approach, landing, and landing roll-out.

Post landing, a sink rate analysis of the STS-92 main landing gear was performed for the main gear touchdown. See Section 2.6.

The drag chute deploy sequence appeared normal on the landing imagery. Venting from the APU vent located at the forward edge of the base of the vertical stabilizer was seen during the landing roll out and after wheel stop. Venting from the APU during landing has occurred on previous missions.

According to the pre-mission agreement, the STS-92 landing films were not screened due to budgetary constraints.

1.2 LANDING EVENTS TIMING

The time codes from videos were used to identify specific events during the screening process. The landing event times are provided in Table 1.2.

STS-92 (OV-103) Film/Video Screening and Timing Summary

STS-92 Landing and Drag Chute Event Times from Video

| Event Description | Time (UTC) | Camera |
|---|-------------------|---------------|
| Main gear door opening | 298:20:59:22.8 | NASA Select |
| Left main gear tire touchdown | 298:20:59:42.0 | NASA Select |
| Right main gear tire touchdown | 298:20:59:42.2 | NASA Select |
| Drag chute initiation | 298:20:59:47.0 | NASA Select |
| Pilot chute at full inflation | 298:20:59:47.9 | NASA Select |
| Bag release | 298:20:59:48.6 | NASA Select |
| Drag chute inflation in reefed configuration | 298:20:59:49.3 | NASA Select |
| Drag chute inflation in disreefed configuration | 298:20:59:52.9 | NASA Select |
| Nose wheel touchdown | 298:20:59:54.6 | NASA Select |
| Drag chute release | 298:21:00:21.8 | NASA Select |
| Wheel stop | 298:21:00:49.3 | NASA Select |

Table 1.2 Landing Event Times

Summary of Significant Events

2. SUMMARY OF SIGNIFICANT EVENTS

2.1 DEBRIS FROM SSME IGNITION THROUGH LIFTOFF

Several pieces of dark-colored debris were seen below the MLP deck prior to SRB ignition. The debris appeared to have come from the area of the SSME flame duct. (Camera E63)



Figure 2.1 (A) Umbilical Ice Debris Contacting LH2 Electric Cable Tray

Multiple pieces of ice debris were seen falling from the ET/Orbiter umbilicals and along the -Z side of the body flap during SSME ignition through liftoff. Several pieces of the debris were seen to contact the Orbiter LH2 umbilical well door sill (23:16:55.209, 23:16:56.777, 23:16:57.077 UTC). Four pieces of ice debris seen

Summary of Significant Events

falling from the forward end of the LH2 ET/Orbiter umbilical contacted the +X surface of the LH2 electric cable tray during SSME ignition. No damage to the launch vehicle was detected. (Cameras OTV009, OTV054, OTV063, E1, E4, E5, E31, E34, E52, E54)

Several pieces of debris (possible birds) were seen near the exhaust cloud moving toward the launch vehicle after SSME ignition. The debris was not seen to contact the vehicle. (Camera KTV4A)



Figure 2.1 (B) Debris from RSRB Flame Duct at Liftoff

Summary of Significant Events

Several light-colored pieces of debris were seen traveling from the area of the RSRB flame duct and away from the launch vehicle after SRB ignition (23:17:01.179 UTC). On camera E7, several pieces of dark-colored debris were seen coming from the RSRB flame duct at liftoff. On cameras E52 and E222, multiple pieces of light-colored debris (including a piece of water baffle material) were seen moving north of the vehicle at liftoff (23:17:02.1 UTC). None of the debris was seen to contact the launch vehicle. (Cameras E1, E4, E7, E52, E222)

On OVT071, a single, light-colored piece of debris was first seen by the LSRB aft nozzle area and traveled in a northerly direction away from the launch vehicle at liftoff (23:17:01.315 UTC). The debris was not seen to contact the vehicle. (Cameras KTV21A, OTV071)

2.2 DEBRIS DURING ASCENT

As observed on previous missions, multiple pieces of debris (too numerous to count) were seen falling aft of the launch vehicle during ascent. The debris were mostly umbilical ice, RCS paper debris, and SRB instafoam. Debris sightings were timed at 23:17:09.68, 23:17:16.01, 23:17:19.11, 23:17:20.708, 23:17:23.832, 23:17:25.801, and 23:17:26.168 UTC. A single piece of debris (probably ice) was seen falling aft along the body flap at 23:17:28.704 UTC. Other examples were: On camera E222, a single large-appearing piece of debris (probably umbilical ice) was seen on the -Z side of the body flap during ascent (23:17:22.653 UTC). One camera E223, a single piece of light-colored debris was seen near the left inboard elevon and fell aft along the inboard edge of the LSRB during the roll maneuver. (Cameras KTV4A, ET207A, ET212A, ET213, E52, E54, E207, E222, E223)

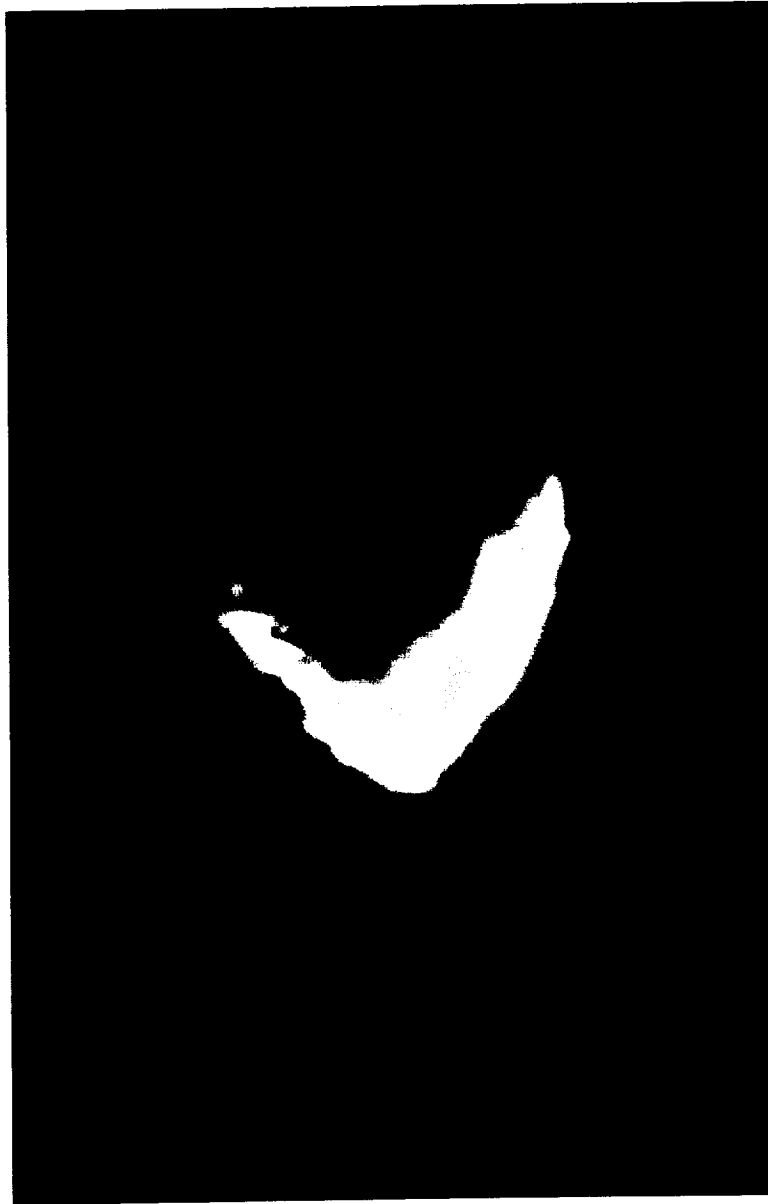


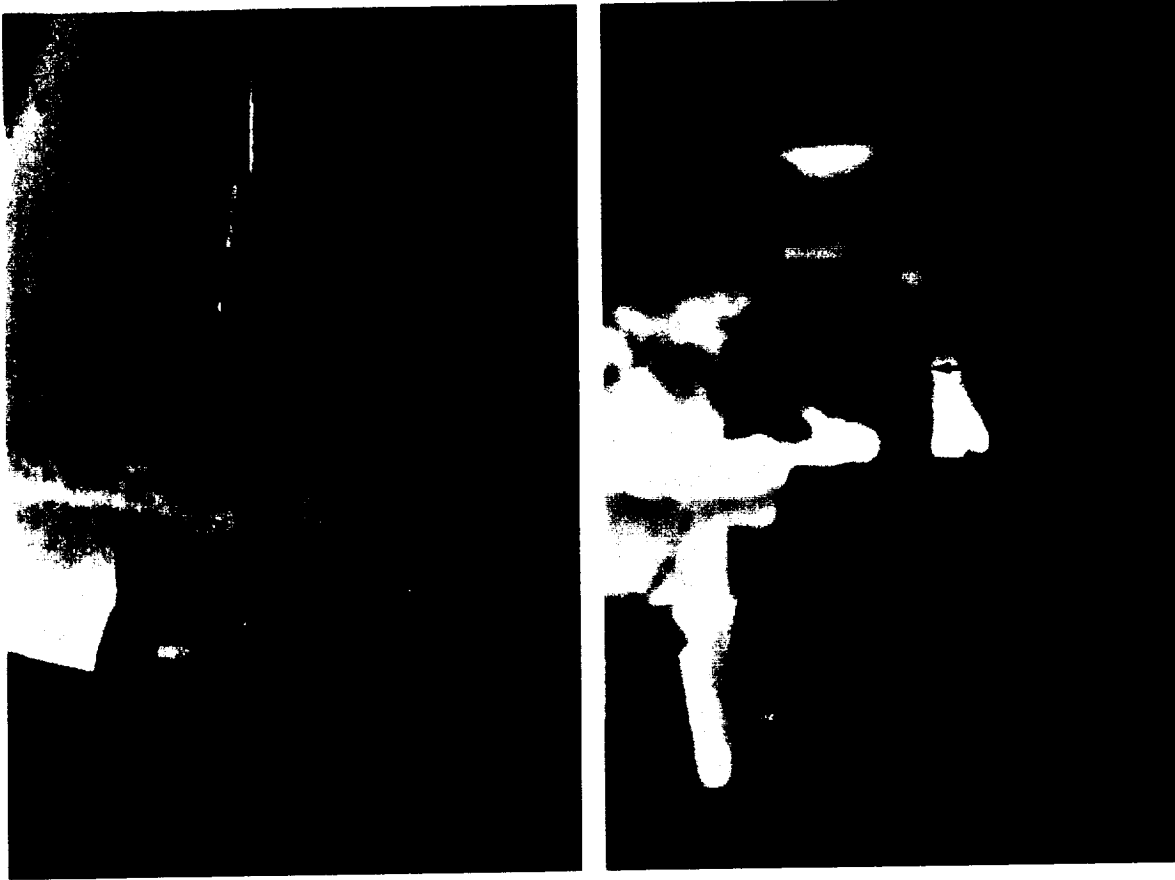
Figure 2.2 Debris Exiting RSRB Exhaust Plume (ET213)

Three light-colored pieces of debris were seen near the SRB exhaust plume during ascent at approximately 70 seconds MET (23:18:10.329, 23:18:10.762, 23:18:11.129 UTC). The identity of the debris was not confirmed, but debris from the SRB exit nozzles (instafoam and slag) has been seen on previous mission films and videos. However, one of the debris pieces seen on STS-92 appeared larger than is typically seen. It was concluded that the large appearance of the debris was caused by soft focus and image motion smear. (Cameras KTV5, KTV21A, ET213)

Summary of Significant Events

2.3 MOBILE LAUNCH PLATFORM (MLP) EVENTS

2.3.1 Anomaly - RSRB Holddown Posts M-2 and M-4 Bolt Hang-ups



Holddown Post M-2 (Camera E8)

Holddown Post M-4 (Camera E7)

Figure 2.3.1 RSRB Holddown Posts M-2 and M-4 Bolt Hang-ups

SRB holddown post stud hang-ups were seen at RSRB holddown posts #2 and #4. Both of the holddown post studs appeared fully extended before they released. The studs appeared to oscillate back and forth (twang) before falling back into the holddown posts. (Cameras E-7, E8)

Holddown post M-2: The approximate time the bolt appeared fully extended was 17:00.583 UTC. The time for the bolt to retract from full extension until the bolt was lost from sight in the holddown post shoe was 0.226 seconds (+/- 0.01 seconds). Using the provided 3.5 inch diameter of the bolt, the visible length of the M-2 bolt was estimated to be approximately 9.1 inches. Several pieces of probable SRB flame duct debris were seen at the time of the bolt hang-up (17:00.425 UTC). A single dark-appearing piece of debris was seen coming from behind the HDP M-2 stud during the hang-up (17:00.636 UTC). The -Y PIC wire from the HDP M-2 remained attached and finally released at 17:00.820 UTC. The HDP M-2 shoe was seen to move slightly upward (+X direction) at the time the bolt released.

Summary of Significant Events

Holddown post M-4: The approximate time the bolt appeared fully extended was 17:00.592 UTC. The time for the bolt to retract from full extension until the bolt was lost from sight in the holddown post shoe was 0.144 seconds (+/- 0.03 seconds). Using the provided 3.5 inch diameter of the bolt, the visible length of the M-4 bolt was estimated to be approximately 9.4 inches. Several pieces of dark debris were seen coming from the SRB flame duct as the RSRB moved upward (17:01.114 UTC).

2.3.2 Mobile Launch Pad Observations



Figure 2.3.2 Orange Vapor Forward of SSME Rims

Orange vapor (possibly free burning hydrogen) was seen forward of the SSME rims, contacting the base heat shield, and extending forward of the aft edge of the OMS pods during SSME ignition (23:16:54.84 UTC). Orange vapor forward of the SSME rims has been seen on previous mission films and videos, particularly on night launches. (Cameras OTV070, E2, E4, E5, E17, E18, E19, E20, E34, E52, E76, E222)

The SSME ignition appeared normal. During SSME start-up, the SSME Mach

Summary of Significant Events

diamonds formed in the expected sequence (3, 2, 1). The times for the Mach diamond formation given below are from camera film E19.

| SSME | TIME (UTC) |
|-------------|-------------------|
| SSME #3 | 23:16:56.916 UTC |
| SSME #2 | 23:16:57.028 UTC |
| SSME #1 | 23:16:57.158 UTC |

Table 2.3 SSME Mach Diamond Formation Times

Faint light-colored streaks, typical of previous missions, were seen extending aft from the SSME nozzle rims prior to and during liftoff (Cameras E2, E5, E52, E76):

SSME #1 - 23:16:57.375, 23:16:58.743, 23:17:01.089 UTC

SSME #2 - 23:17:01.223 UTC

SSME #3 - 23:16:58.395, 23:17:00.165 UTC

Typical of previous missions, small areas of tile surface coating material erosion were seen on the base heat shield outboard of SSME #2, near SSME #1, near the -Y OMS nozzle, on the base of the -Y RCS pod, and on the tip of the -Y RCS stinger prior to liftoff. (Cameras E17, E18, E19, E20, E31, E76)

One tile on the Orbiter left wing appeared unusually bright during liftoff. However, as the vehicle continued upward the bright appearance of the tile disappeared indicating that this was only an effect of the lighting. (Camera E36)

Vapor and ice were seen during the retraction of the GH2 vent arm at liftoff. Frost was seen on the face of the ET GH2 carrier attach plate as the GH2 vent arm pulled away. At least two pieces of frost/ice debris bounced off the LSRB during the GH2 vent arm retraction. No damage to the LSRB was noted. (Camera E33)

PIC firing (SRB ignition) was timed at 23:17:00.022 UTC on HDP M-6, camera film E13.

Both the left and right SRB GN2 purge line separated cleanly from the aft skirts and appeared intact during the time period they were visible before being obscured by exhaust plume.

Summary of Significant Events

2.4 ASCENT EVENTS

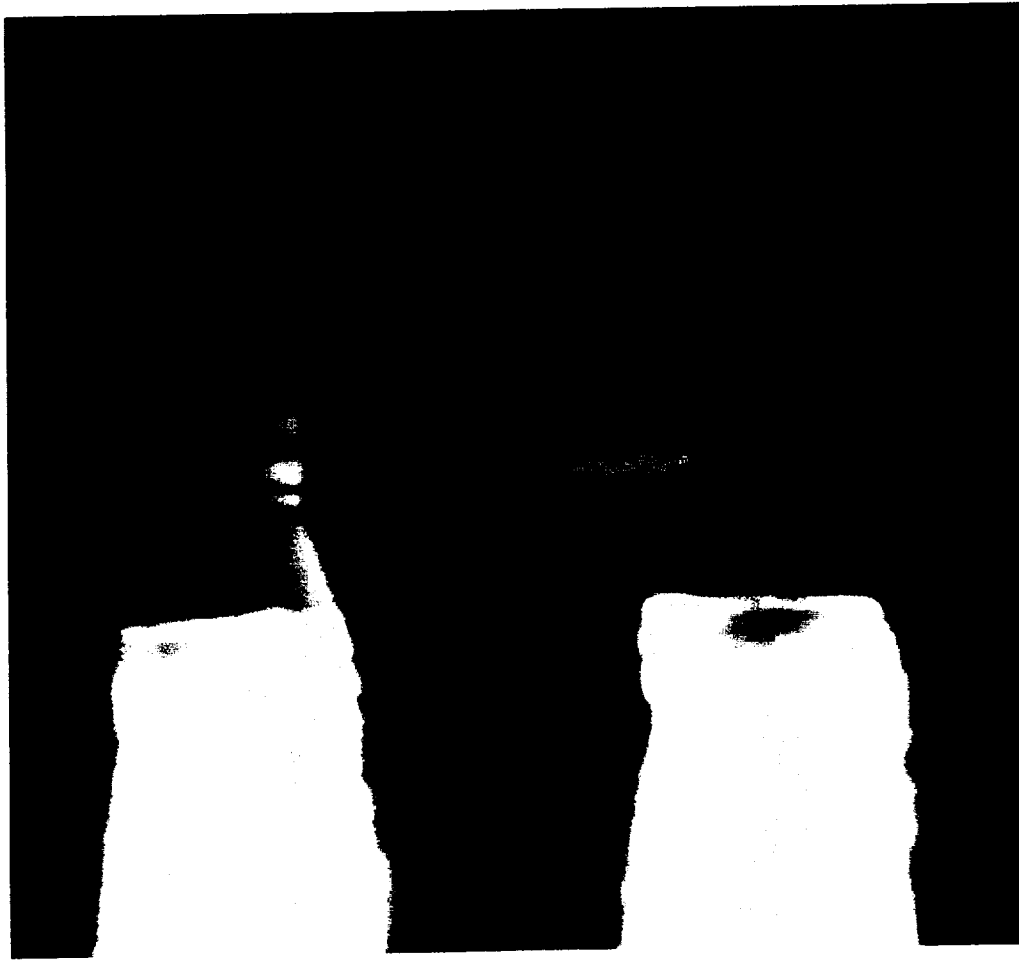


Figure 2.4 (A) Vapors Aft of ET Aft Dome

The outgassing and vapors aft of the ET aft dome during early ascent appeared more extensive than typical missions. KSC reported that the vapors from the ET aft dome were caused by outgassing of dry TPS (rather than condensate vaporizing). (Camera ET207A)



Figure 2.4 (B) Flares in the SSME Exhaust Plume (Camera E222)

Multiple small, light-colored flares were seen in the SSME exhaust plume during ascent (23:17:07.946, 23:17:13.20, 23:17:15.958, 23:17:17.559, 23:17:19.846, 23:17:32.341, 23:17:34.987, 23:17:51.0 UTC). Some of these flares were induced by umbilical ice and RCS paper debris. Also, a white flash and several light-colored possible pieces of debris were seen in the +Z direction from the SSME #1 exhaust plume just prior to the appearance of a flare (23:17:18.645 UTC). Light-colored flares in the SSME exhaust plume have been noted on previous mission launch imagery. Often on previous mission imagery, debris has been seen contacting the SSME exhaust plume resulting in visible flares. Usually this debris appeared to be RCS paper. (On STS-26 and STS-101, debris that resulted in very large orange-colored flares was determined to have been tile material.) (Cameras KTV4A, ET207A, ET212A, ET213, E207, E212, E222, E223, E224)

Multiple white-colored flashes (probably an atmospheric effect) were seen near the SSME exhaust plume during ascent (23:17:21.041 UTC). (Cameras ET213)

Summary of Significant Events

Umbilical purge barrier material on both of the LH2 and LO2 ET/Orbiter umbilicals was partially detached and flapping against the Orbiter tiles during the roll maneuver and beyond. (Cameras E207, E212)

Body flap motion was seen during ascent with the amplitude and frequency of the motion appearing similar to that seen on previous mission imagery (23:17:40 UTC) (Cameras ET207, E207)

2.5 ONBOARD PHOTOGRAPHY OF THE EXTERNAL TANK (ET-104)

No External Tank or SRB separation photography was acquired on STS-92. The 35mm umbilical well TPS camera film was unusable due to the nighttime conditions at ET separation. The two 16mm umbilical well camera films were disabled preflight because of the investigation into an electric short problem.

No attempt was made by the crew to take the handheld 35 mm film and the handheld video of the ET because of the pre-flight decision not to acquire this photography because of the expected nighttime conditions.

2.6 LANDING SINK RATE ANALYSIS

Image data from the EL1009 16mm motion picture camera on runway 22 at Edwards Air Force Base was used to determine the landing sink rate for STS-92. This camera has a 100mm lens and is located on the side of the runway in the 3R position. (This view is considerably different from the nominal camera view used to determine sink rate for landings at Kennedy Space Center, which is a view aimed straight down the runway). The sink rates of the orbiter main gear, nose gear, and a point midway between the two gears were measured over the final second prior to touchdown of the left main gear. Data points defining the top and bottom of the left main gear tires were collected on every frame (100 frames) along with points defining the bottom of the right main gear tires, the bottom of the nose gear tires, and a corresponding point on the runway directly below each gear. The distance from the top and bottom of the left main gear tire was used to determine a scaling factor. The height of each gear above the runway was calculated by the vertical difference between the bottom of the tires and the corresponding ground point. An assumption was made that the line of sight of the camera was parallel to the horizon and that the error in picking the ground points on the runway was small.

Straight lines were fit to the data for the final one-second, the final half-second, and the final quarter-second prior to touchdown of the left main gear. The slope of these lines define the sink rate for each interval and are listed in Table 2.6 along with the associated uncertainties based on the line fits. A plot describing these sinkrates is shown in Figure 2.6 (A).

Summary of Significant Events

| Time Prior to Touchdown | Left Main Gear Sink Rate | Estimated Error (1σ) |
|-------------------------|--------------------------|-------------------------------|
| 1.00 Sec. | 4.9 ft/sec | ± 0.1 ft/sec |
| 0.50 Sec. | 4.8 ft/sec | ± 0.2 ft/sec |
| 0.25 Sec. | 5.2 ft/sec | ± 0.5 ft/sec |

Table 2.6 Main Gear Landing Sink Rate

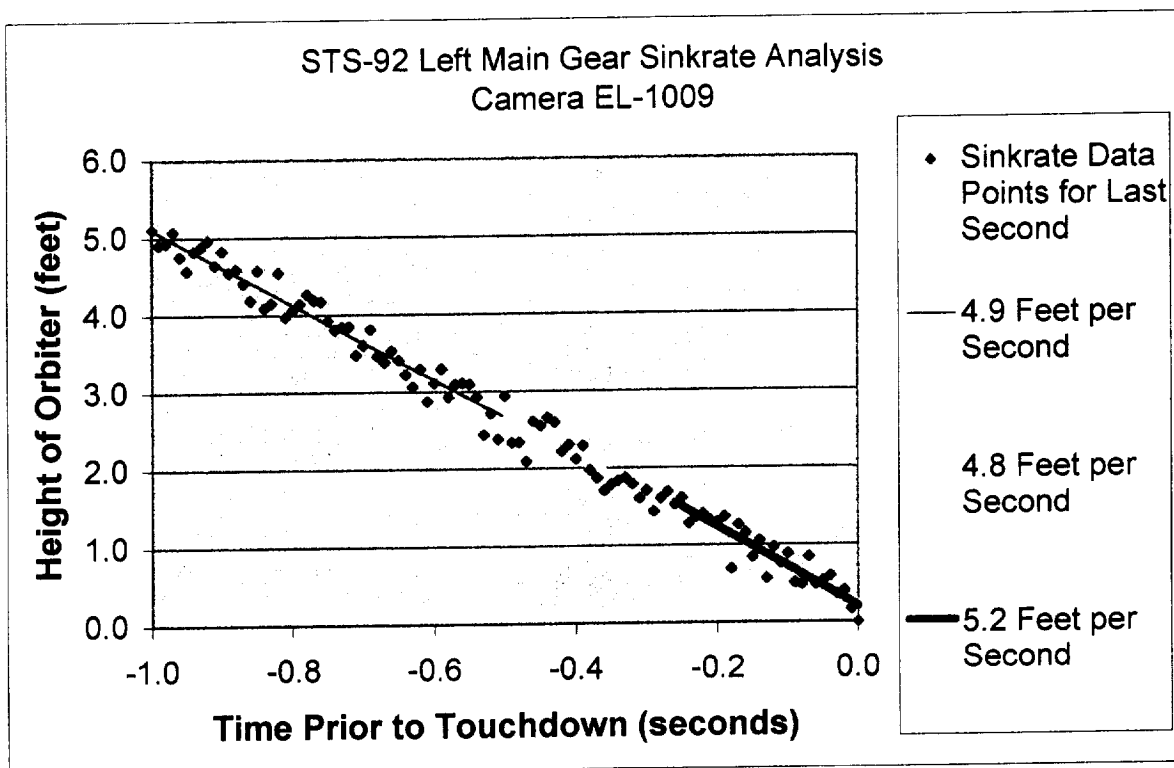


Figure 2.6 (A) Main Gear Landing Sink Rate

The maximum allowable main gear sink rate values are 9.6 feet/second for a 212,000 lb. vehicle and 6.0 feet/second for a 240,000 lb. vehicle. The landing weight of the STS-92 vehicle was estimated to be 205,123 lbs.

Summary of Significant Events

2.7 OTHER

2.7.1 Normal Events

- elevon motion prior to liftoff
- RCS paper debris from SSME ignition through liftoff
- ET twang
- ice and vapor from the LO2 and LH2 TSM T-0 umbilical prior to and after disconnect
- Multiple pieces of ET/Orbiter umbilical ice debris falling along the body flap during liftoff
- vapor off the SRB stiffener rings
- acoustic waves in the exhaust cloud during liftoff
- debris in the exhaust cloud (including water baffle material) after liftoff
- expansion waves after liftoff
- charring of the ET aft dome
- ET aft dome outgassing
- roll maneuver
- linear optical effects
- recirculation
- SRB plume brightening
- SRB slag debris before, during, and after SRB separation

2.7.2 Normal Pad Events

Normal pad events observed included:

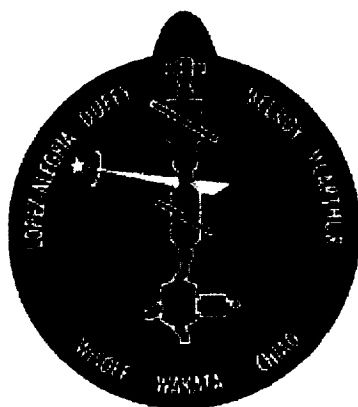
- hydrogen burn ignitor operation
- FSS and MLP deluge water activation
- sound suppression system water operation
- GH2 vent arm retraction
- TSM T-0 umbilical operations
- LH2 and LO2 TSM door closures

APPENDIX B. MSFC PHOTOGRAPHIC ANALYSIS SUMMARY



Space Shuttle Mission STS-92

Engineering Photographic Analysis Summary Report Marshall Space Flight Center



*T. J. Rieckhoff (NASA/MSFC)
M. Covan (USA)
J.M. O'Farrell (USA)*

*Marshall Space Flight Center,
Huntsville, AL 35812*

Contents

| | |
|---|----|
| 1. Engineering Photographic Analysis Summary Report for STS-92..... | 3 |
| 2. Photographic Coverage..... | 3 |
| 3. Anomalies..... | 3 |
| 4. T-Zero Times..... | 3 |
| 5. SRB Separation Timing..... | 4 |
| 6. Individual Camera Assessments..... | 4 |
| 6.1 Video Camera Assessments..... | 4 |
| 6.2 Film Camera Assessments..... | 4 |
| 7. Observations..... | 6 |
| 7.1 Video Camera OTV070..... | 6 |
| 7.2 Video Camera TV4A..... | 7 |
| 7.3 Video Camera TV5..... | 8 |
| 7.4 Video Camera ET207..... | 9 |
| 7.5 Video Camera OTV009..... | 10 |
| 7.6 Film Camera E7..... | 11 |
| 7.7 Film Camera E8..... | 12 |
| 7.8 Film Camera E52..... | 13 |
| 8. Special Investigations..... | 14 |
| 8.1 First Vertical Motion of STS-92 SRBs..... | 14 |
| 8.2 Cork damage on the Right SRB..... | 15 |

FIGURES

| | |
|--|----|
| Figure 1. OTV070: Free Burning Hydrogen..... | 6 |
| Figure 2. TV4A: Pad Debris at Liftoff..... | 7 |
| Figure 3. TV5: Debris Ejected from SRB Exhaust Plumes..... | 8 |
| Figure 4. ET207: Debris Induced Streak in SSME Exhaust Plumes..... | 9 |
| Figure 5. OTV009: Ice Striking Cable Tray..... | 10 |
| Figure 6. E7: Stud Hang-up at Holddown Post M-4..... | 11 |
| Figure 7. E8: Stud Hang-up at Holddown Post M-2..... | 12 |
| Figure 8. E52: Engine Streak on SSME#1..... | 13 |
| Figure 9. Camera Positions on Mobile Launch Platform..... | 14 |
| Figure 10. First Motion of STS-92 SRBs..... | 15 |

1. Engineering Photographic Analysis Summary Report for STS-92



Launch of the one-hundredth space shuttle mission, STS-92, the twenty-eighth flight of the Orbiter Discovery (OV-103), occurred October 11, 2000, at approximately 6:17 PM Central Daylight Time from launch complex 39A, Kennedy Space Center (KSC), Florida. Launch time was reported as 285:23:17:00.011 Universal Coordinated Time (UTC) by the MSFC Flight Evaluation Team.

Photographic and video coverage has been evaluated to determine proper operation of the flight hardware. Video and high-speed film cameras providing this coverage are located on the fixed service structure (FSS), mobile launch platform (MLP), perimeter sites, Eastern Test Range tracking sites and onboard the vehicle. Additional information concerning photographic analysis of this and previous space shuttle missions is available on the MSFC Engineering Photographic Analysis website at URL:

<http://photo4.msfc.nasa.gov/STS/sts92/sts92.html>.

2. Photographic Coverage

Sixty engineering photographic products consisting of launch video, ground-based engineering films and onboard film and video were received and reviewed at MSFC. Five video cameras and seven film cameras experienced intermittent to total loss of vehicle due to clouds and/or tracking error. Six video cameras and two film cameras experienced overexposure or focus problems. Two film cameras experienced problems with timing. Camera coverage received at MSFC for STS-92 is illustrated in the following table.

| | 16mm | 35mm | Video |
|-----------|------|------|-------|
| MLP | 18 | 0 | 4 |
| FSS | 5 | 0 | 3 |
| Perimeter | 0 | 5 | 4 |
| Tracking | 0 | 10 | 11 |
| Onboard | 0 | 0 | 0 |
| Totals | 23 | 15 | 22 |

The Photographic Acquisition Disposition Document (PADD) and information regarding individual camera status and assessments may be found on the website.

3. Anomalies

Two Holddown Post stud hang-ups occurred on Mission STS-92. One hang-up, on Holddown Post M-2, was captured by film camera E8. The other hang-up was on Holddown Post M-4 and captured by film camera E7. In both situations, the stud was held fully extended until the vehicle lifted by the stud. The bolt then centered itself vertically and dropped back into the SRB Holddown Post. Images of each stud hang-up are available in the Observations section below.

4. T-Zero Times

T-Zero times are determined from MLP cameras that view the SRB holddown posts numbers M-1, M-2, M-5, and M-6. These cameras record the explosive bolt combustion products.

| Holddown Post | Camera Position | Time (UTC) |
|---------------|-----------------|------------------|
| M-1 | E9 | 285:23:17:00.020 |
| M-2 | E8 | 285:23:17:00.019 |
| M-5 | E12 | 285:23:17:00.020 |
| M-6 | E13 | 285:23:17:00.019 |

5. SRB Separation Timing

SRB separation time, as recorded by observations of the BSM combustion products from long-range cameras E207 and E212, occurred at approximately 285:23:19:03.035 UTC.

6. Individual Camera Assessments

Notable assessments for individual cameras are listed below. The complete assessments for all individual cameras for flight STS-92 may be found on the website.

6.1 Video Camera Assessments

TV2 - Vehicle obscured by clouds.
TV5 - Early vehicle ascent was overexposed. Five debris objects were observed near 70 seconds MET from SRB exhaust during ascent. Soft focus made these debris objects appear larger than normally observed from this typical occurrence.
TV11 - Good view of moon and clouds during launch.
TV13 - Camera acquired vehicle as it entered the clouds. No engineering data available from this camera.
TV4A - Free hydrogen impingement on OMS Pod observed. Aft end of vehicle overexposed during early ascent. Vapor trail from wing noted. Vehicle intermittently obscured by clouds.
TV7A - Typical SRB trench debris noted at liftoff.
ET204 - Vehicle intermittently to mostly obscured by clouds.
ET207 - Debris induced streak in SSME plumes observed at 285:23:17:49 UTC. Flow recirculation observed. SRB separation time at 285:23:19:03 UTC.
ET208 - Vehicle obscured by clouds. No engineering data available.
ET212 - SRB separation: 285:23:19:03.04 UTC. Vehicle overexposed prior to roll maneuver. Several streaks observed in SSME plumes near end of roll maneuver.
ET213 - Debris ejected from SRB plumes.
TV21A - Debris ejected from SRB plumes.
OTV009 - Ice falls from the LH2 17 inch disconnect striking the door sill, no damage observed. Purge barrier material observed flapping.
OTV051 - Camera overexposed. No details can be discerned during SSME ignition and liftoff.
OTV060 - Soft focus on camera. Camera vibration and exposure fluctuation problems.
OTV061 - Video somewhat overexposed. Little detail available after mid-body goes through field of view.
OTV063 - Typical ice/frost from 17 inch disconnects. Ice noted bouncing off cable tray, no damage visible. Purge barrier material noted flapping.
OTV070 - Free Hydrogen impinges on the right(+Y) Stinger Pod and OMS Pod. Interior of SSME nozzles and plumes overexposed, no details observable.
OTV071 - Pad debris from SRB exhaust observed, reported as SRB throat plug material.

6.2 Film Camera Assessments

E1 - Typical ice/frost from 17-inch disconnects. Debris object observed at liftoff moving from Left SRB Secondary Flame Trench away from vehicle.
E2 - Free burning Hydrogen noted impinging on Stinger and OMS Pod. Engine streaks in SSME#1 noted at 285:23:16:58.743 UTC, 285:23:16:59.019 UTC, 285:23:16:59.655 UTC, and 285:23:17:00.210 UTC. Probable debris induced streak noted in SSME#1 plume at 285:23:17:01.089 UTC.
E3 - Engine streaks in SSME #1 at similar times as observed on E2. Streak seen in SSME#1 plume at 285:23:17:01.089 UTC confirmed as engine streak.
E4 - Pad debris noted rising and falling. Typical ice/frost from 17-inch disconnects. Engine streak observed in SSME#3 at 285:23:16:56.303 UTC.
E6 - Typical ice/frost from 17-inch disconnects.
E7 - Pad debris noted rising and falling. SRB Holddown bolt on Post M4 was visible after SRB ignition. The bolt was fully extended leaning away from the vehicle. Bolt moved back into centered vertical

- position and fell back into Holddown Post shoe bore. A small debris object was observed after bolt separation from Holddown Post foot.
- E8 - SRB Holddown stud on Post M2 remains fully extended until SRB Holddown Post Foot separates from Shoe. Bolt then moves back to centered vertical and drops into Holddown Post Shoe bore. PIC firing time observed to be 285:23:17:00.019 UTC. GN2 purge line appears normal. Typical pad debris.
 - E9 - Pad debris noted rising and falling. PIC Firing time for Holddown Post M1 was noted to be 285:23:17:01.020 UTC.
 - E11 - Pad debris noted rising and falling.
 - E12 - Typical ice/frost from 17-inch disconnects. SRB Holddown Post M5 PIC Firing time noted at 285:23:17:00.020 UTC.
 - E13 - SRB Holddown Post M6 PIC Firing time was noted at 285:23:17:00.019 UTC.
 - E14 - Lot of foam debris observed.
 - E16 - Pad debris noted rising and falling. Film overexposed at liftoff, no details discernable until after vehicle leaves field of view.
 - E19 - Engine streaks noted in SSME#1 plumes at 285:23:17:00.210 UTC and 285:23:16:58.743 UTC. Plume brightening in SSME#3 at 285:23:16:56.303 UTC appears to be normal SSME startup. Mach diamond formation was observed to be in 3-2-1 order.
 - E20 - Engine streak in SSME#2 observed. Engine streak in SSME#1 observed. Timing in error.
 - E60 - Pad debris noted rising and falling. Typical ice/frost from 17-inch disconnects.
 - E62 - Typical debris associated with SRB ignition. Film overexposed soon after liftoff.
 - E204 - Vehicle obscured by clouds for most of ascent. No engineering data available.
 - E205 - Flow recirculation noted. Vehicle intermittently obscured by clouds.
 - E31 - Typical ice/frost from LH2 disconnect. Ice noted striking the ET cable tray.
 - E33 - Frost remains around ETCA after separation. Ice ejected from ETCA appears to rebound from SRB.
 - E34 - Pad debris noted rising and falling.
 - E36 - Debris item noted ejected from right SRB flame trench.
 - E52 - Pad debris noted rising and falling. Typical debris observed falling aft of vehicle. Debris-induced streak in SSME plume. Typical ice/frost from 17-inch disconnects. Free Hydrogen impinges on OMS Pod. SSME #1 Engine streaks observed at: 285:23:16:58.744, 285:23:17:00.210, 285:23:17:04.92, 285:23:16:57.474, 285:23:17:01.088, and 285:23:17:01.243 UTC.
 - E54 - Pad debris noted rising and falling. Timing block display shows double images.
 - E63 - Pad debris noted rising and falling. "Bump" on left wing of Orbiter appears on wing pre-launch.
 - E207 - Typical debris observed falling aft of vehicle. Glowing debris particles ejected from SRB plume prior to, during and after separation. Debris-induced streaks in SSME plume. Vapors from Orbiter wingtip noted early in flight. Linear optical distortions noted. Flow recirculation noted. Vehicle partially obscured by clouds. Thermal curtain motion noted.
 - E208 - Erratic tracking. Vehicle obscured by clouds. No engineering data available.
 - E212 - Typical debris observed falling aft of vehicle. Glowing debris particles ejected from SRB plume prior to, during and after separation. Vehicle partially obscured by clouds. Flapping purge barrier material around LH2 and LO2 disconnect observed. "Bump" on left wing noted. Brown spot on forward upper section of OMS Pod noted. JSC has been informed of these observations.
 - E213 - Debris-induced streaks in SSME plume. Bump on upper surface of left wing, forward of the outboard elevon of Orbiter, noted. Light brown spot on left OMS Pod noted. Typical debris falling aft of vehicle. Glowing debris ejected from SRB plume.
 - E220 - Typical debris observed falling aft of vehicle. Vehicle partially obscured by clouds. Purge barrier material around LH2 disconnect noted. Vapors from orbiter wingtip noted. Glowing debris ejected from SRB plume prior to separation. Two green-colored debris streaks noted in SSME plumes. Reddish-orange debris streak noted in SSME plume.
 - E222 - Pad debris noted rising and falling. Typical debris observed falling aft of vehicle. Debris-induced streaks in SSME plume. Vehicle partially obscured by clouds. Vapors from Orbiter wing noted.
 - E223 - Debris-induced streaks in SSME plume. Clouds obscure vehicle for major portion of ascent.
 - E224 - Debris-induced streaks in SSME plume. Vehicle partially obscured by clouds. Large debris object visible at liftoff moving away from vehicle, apparently from the right SRB flame trench.

7. Observations

7.1 Video Camera OTV070

Free burning Hydrogen was observed to impinge on the right Stinger and OMS pods during SSME startup.

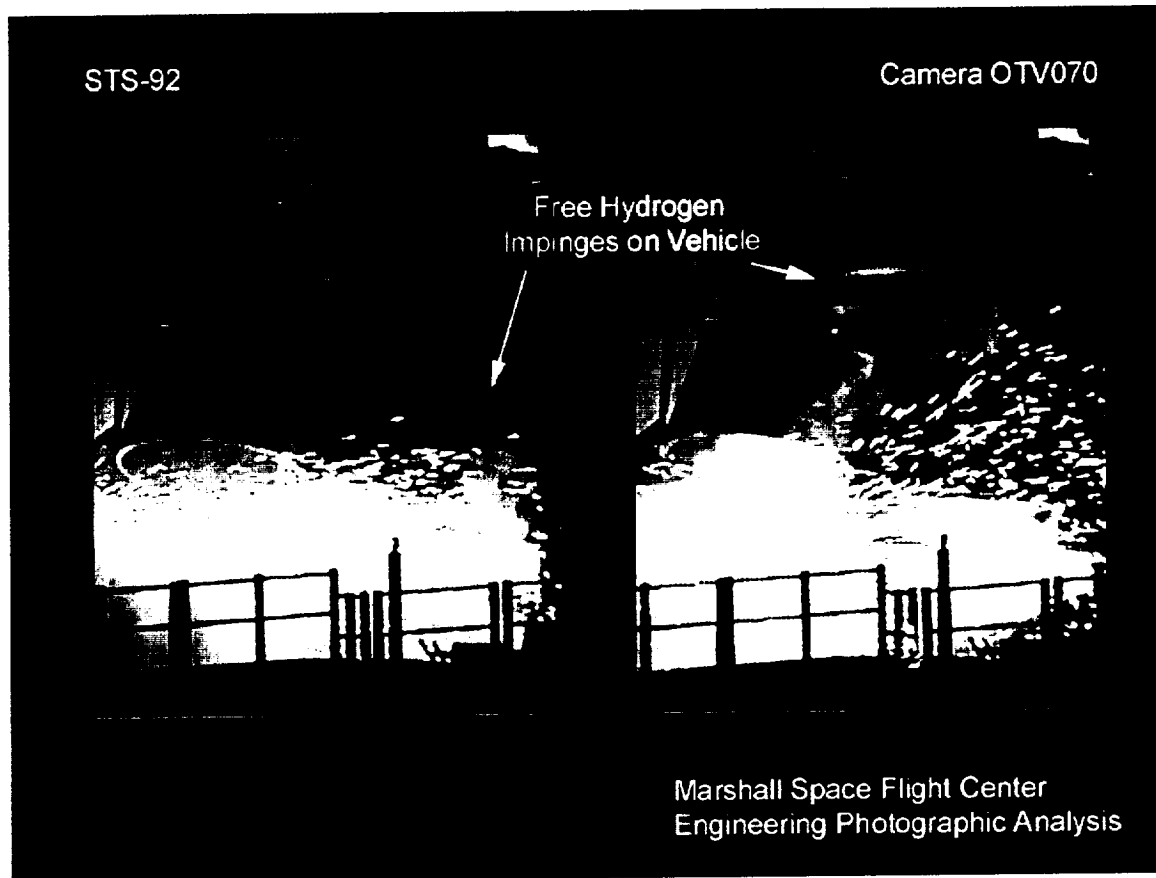


Figure 1. OTV070: Free Burning Hydrogen

7.2 Video Camera TV4A

Typical pad debris was observed moving away from the vehicle during liftoff.

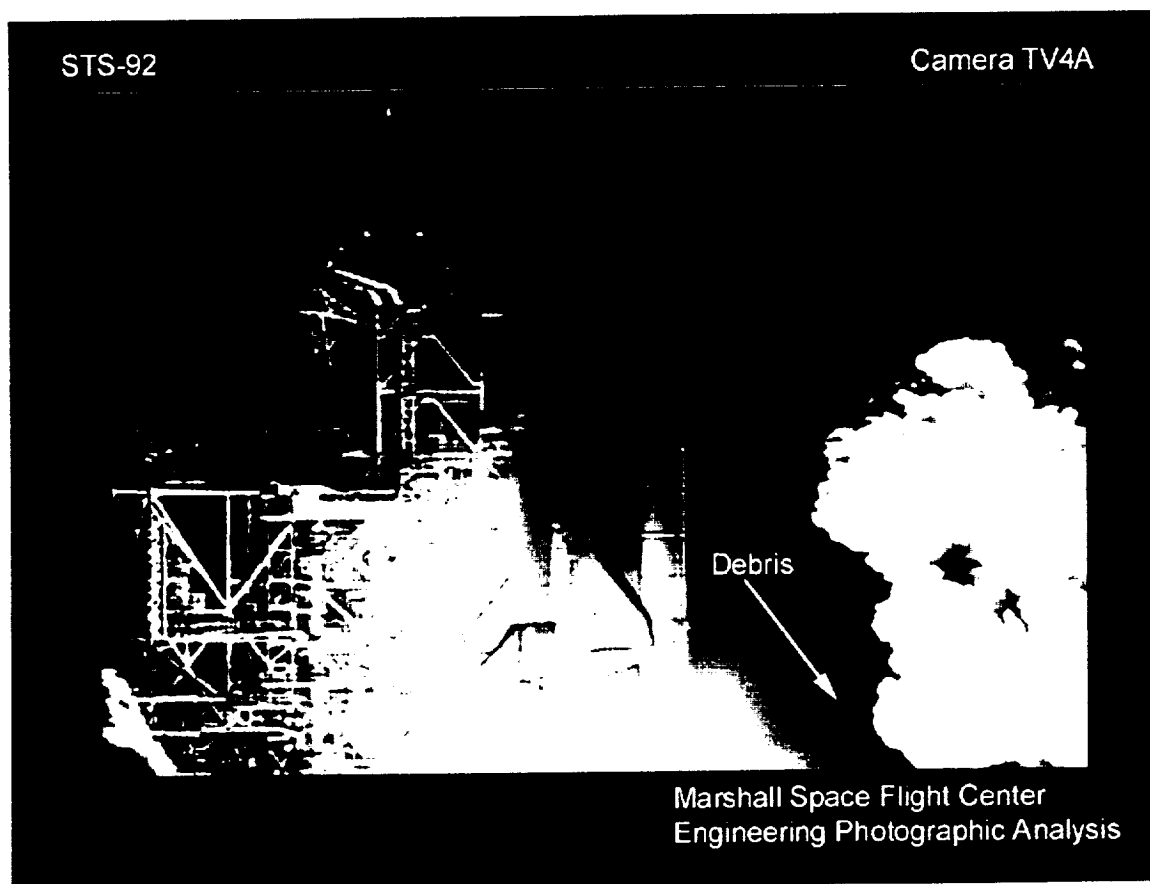


Figure 2. TV4A: Pad Debris at Liftoff

7.3 Video Camera TV5

During night launches, debris is often seen being ejected from the SRB exhaust plumes. Several such debris objects were noted during ascent for STS-92 mission. Figure 3 depicts debris being ejected from the SRB plumes as viewed from video camera TV5. Because the camera experienced soft focus the debris objects appear larger than they actually are. Insets in Figure 3 enlarge and contrast the debris observed.

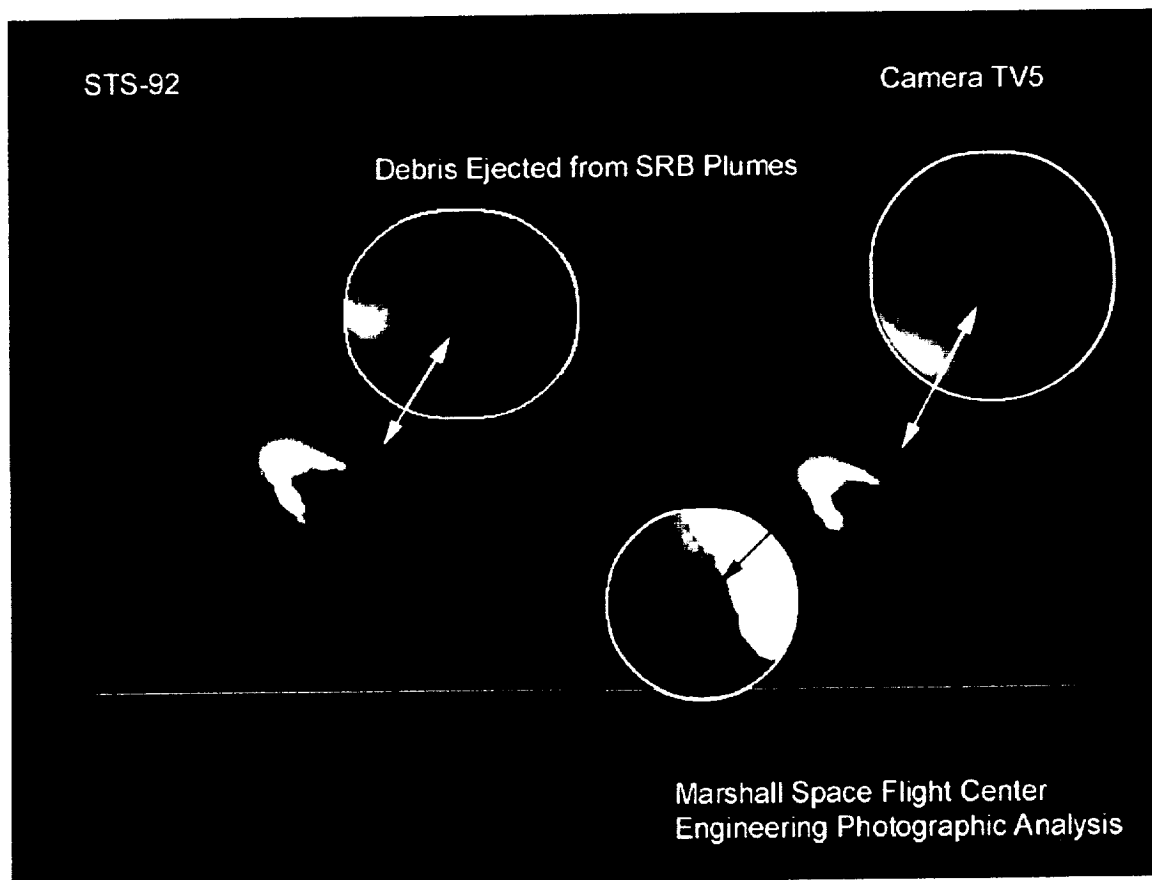


Figure 3. TV5: Debris Ejected from SRB Exhaust Plumes

7.4 Video Camera ET207

Debris induced streaks in SSME exhaust plumes were noted on seven film cameras and one video camera. Debris falling aft of the vehicle is common and streaks generated by interaction of this debris with the SSME plumes are also quite common. The streak noted by video camera ET207, Figure 4, occurred at approximately 285:23:17:49 UTC.

There were two streaks that appeared green-colored and another streak that had a reddish tinge to it in film footage from camera E207. Paper was probably the source of the streak with the reddish tinge. The source of the green-colored streaks is unknown.

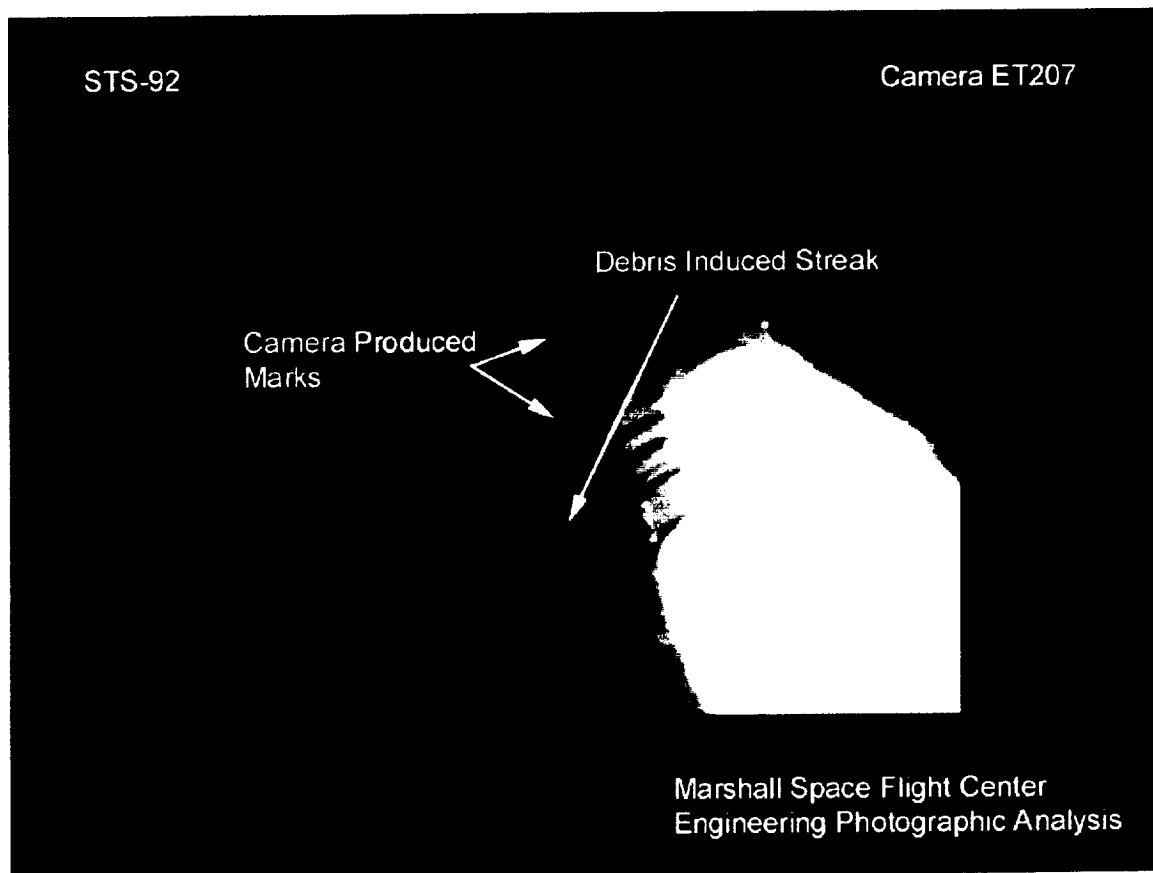


Figure 4. ET207: Debris Induced Streak in SSME Exhaust Plumes

7.5 Video Camera OTV009

Ice and frost regularly accumulate around the LH2 and LO2 17.0 inch disconnects prior to launch. In Figure 5 ice debris was captured as startup vibrations loosened it from around the LH2 disconnect and as it subsequently struck the cable tray. No damage was observed to the cable tray.

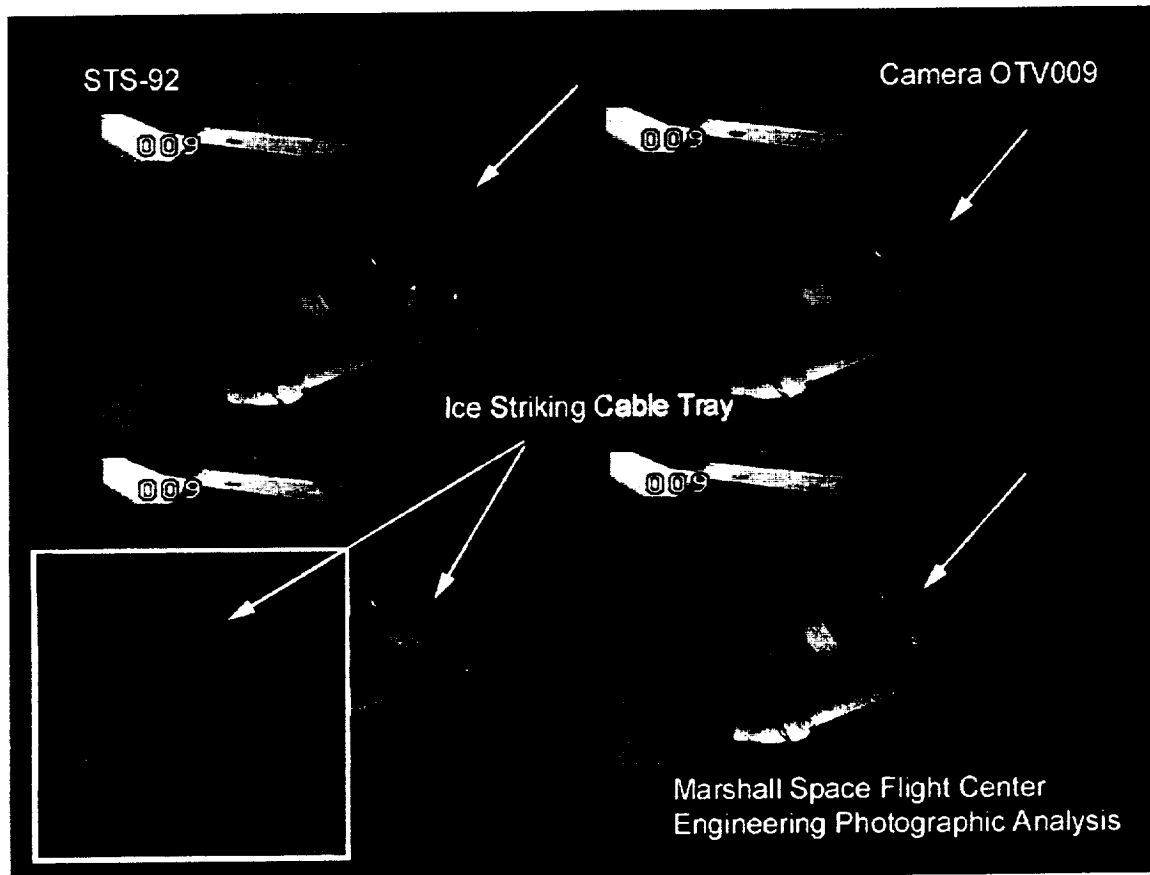


Figure 5. OTV009: Ice Striking Cable Tray

7.6 Film Camera E7

A stud hang-up occurred at Holddown Post M-4. A small piece of debris was imaged in Figure 6, which appeared to be ejected from the Holddown Post hole. Camera positions on the MLP are illustrated in Figure 9.

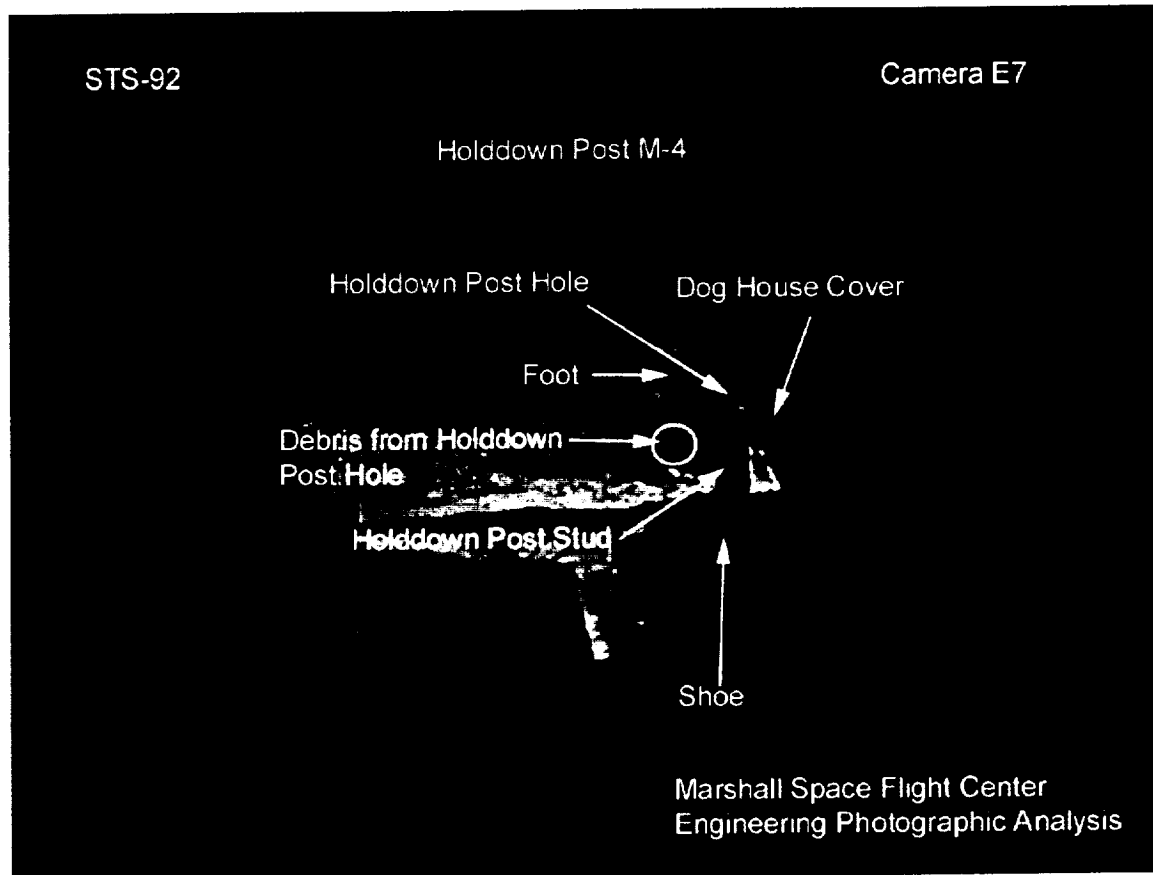


Figure 6. E7: Stud Hang-up at Holddown Post M-4

7.7 Film Camera E8

A stud hang-up occurred at Holddown Post M-2. Camera positions on the MLP are illustrated in Figure 9.

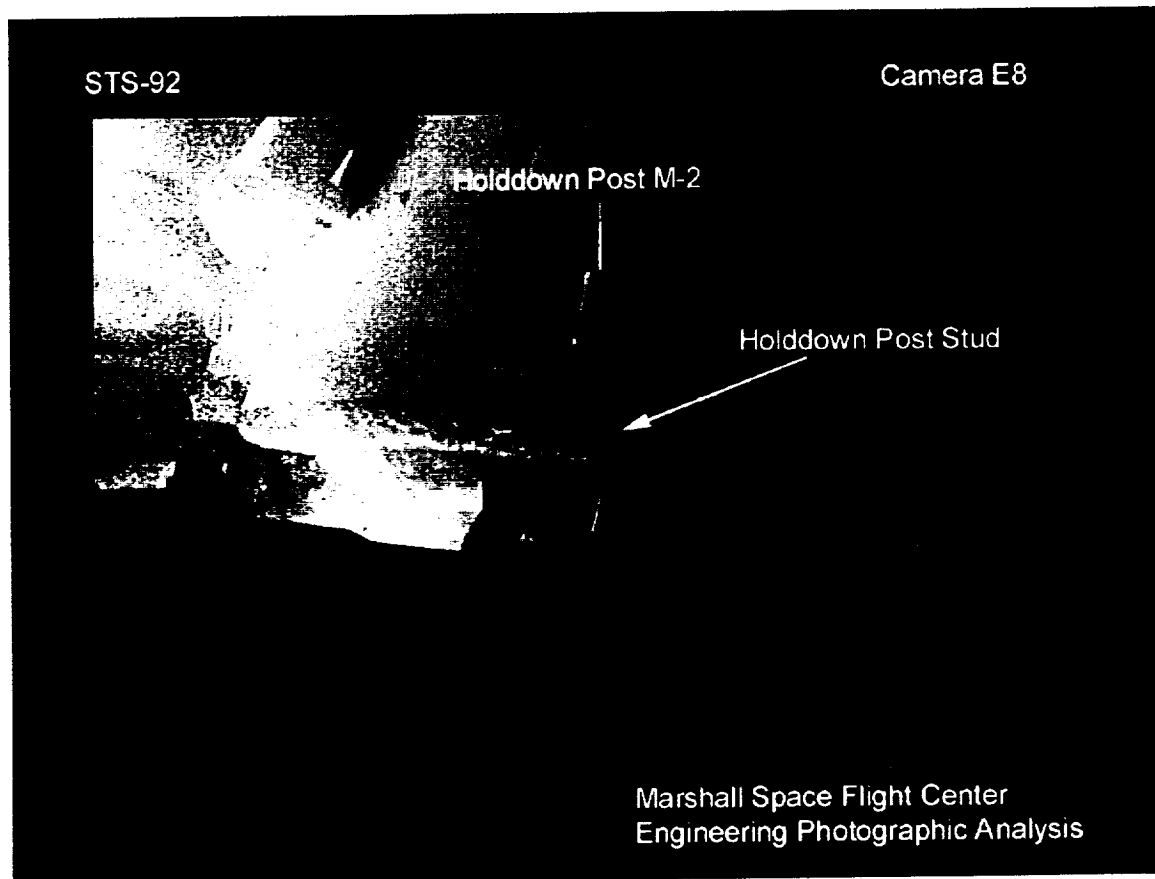


Figure 7. E8: Stud Hang-up at Holddown Post M-2

7.8 Film Camera E52

Engine streaks noted in SSME#1 exhaust plumes after mainstage was attained and before liftoff are listed in the following table.

| Time (UTC) | Engine | Camera |
|----------------------|--------|-------------|
| 285:23:16:57.474 | SSME#1 | E52 |
| 285:23:16:58.743-744 | SSME#1 | E2, E19,E52 |
| 285:23:16:59.019 | SSME#1 | E2, E19,E52 |
| 285:23:16:59.655 | SSME#1 | E2 |
| 285:23:17:00.210 | SSME#1 | E2 |
| 285:23:17:01.088-089 | SSME#1 | E2, E3,E52 |
| 285:23:17:01.243 | SSME#1 | E52 |
| 285:23:17:04.92 | SSME#1 | E52 |

Camera E20 also observed engine streaks in SSME #1 and SSME #2, but these streaks were not timed, due to the timing error on the film.

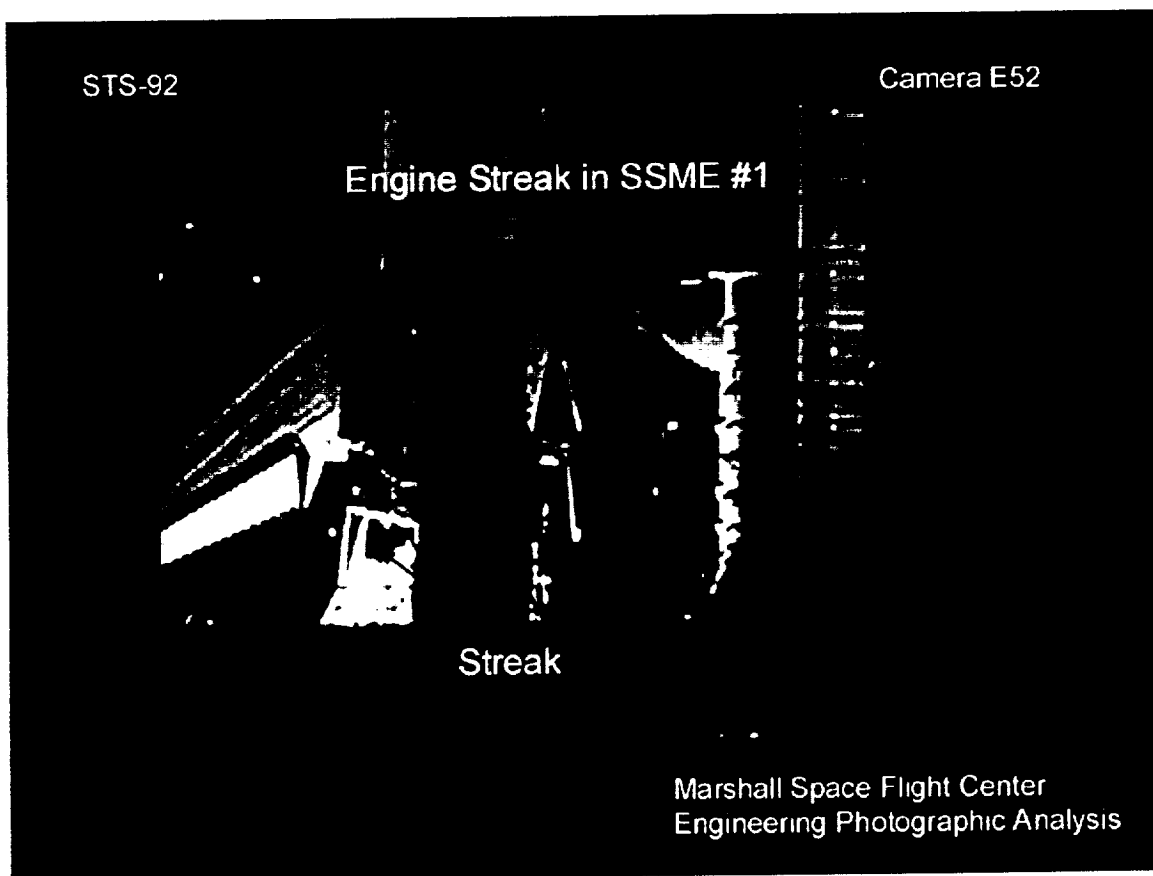


Figure 8. E52: Engine Streak on SSME#1

8. Special Investigations

8.1 First Vertical Motion of STS-92 SRBs

Two stud hang-ups were observed on SRBs for STS-92 at liftoff. MSFC SRB Project Office requested Engineering Photographic Analysis provide an estimate of the time of first vertical motion as recorded from STS-92 launch films. Results of the investigation were delivered to Brian Pung (MP41).

A single point on each SRB Aft Skirt was tracked with two film cameras. Film camera E8 followed a point on the SRB at Holddown Post M-2 and Film camera E13 followed a point on the SRB at Holddown Post M-6. Although the stud hang-up occurred on Holddown Post M4, film from Camera E7 was too dark to follow a point in the field of view until after firing of the SRBs. Camera Positions for E8 and E13 are noted in Figure 9.

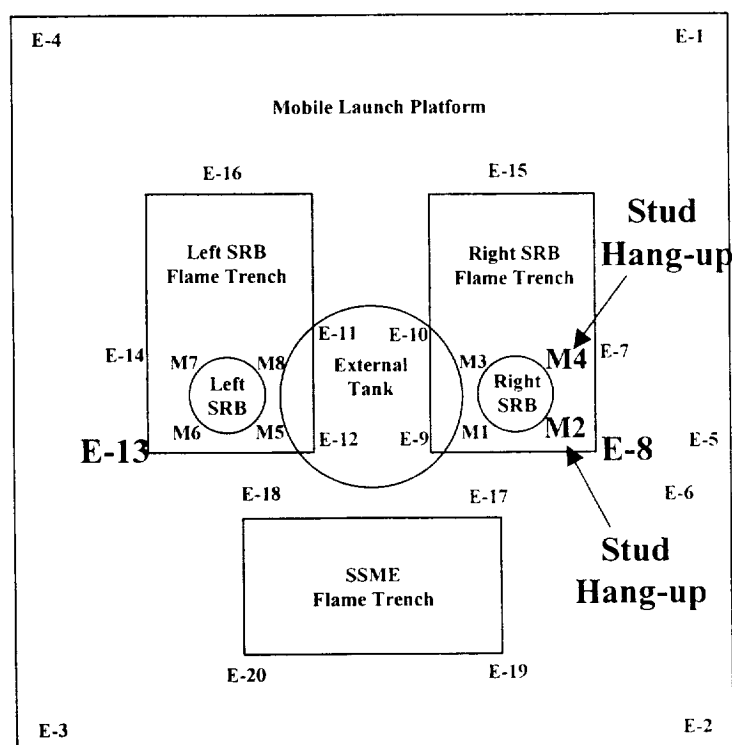


Figure 9. Camera Positions on Mobile Launch Platform

The launch time (T0) was reported by the FEWG as 285:23:17:00.011 UTC and PIC Firing times as observed by Engineering Photographic Analysis are 285:23:17:00.019-020 UTC.

Film Cameras E8 and E13 are high-speed (400 fps ~ 0.0025 seconds per frame) 16mm cameras. Film motion Analyzers were employed to track a point on each SRB for approximately 0.5 seconds, starting from 285:23:17:00.001 UTC, which is prior the PIC Firing Time.

Time on the graph in Figure 10 is in seconds from 285:23:17:00.001 UTC. The Y-coordinates are in film analyzer screen units and are directly related to vertical motion of the SRB. First Vertical Motion is estimated at 285:23:17:00.264 UTC as determined by plotting SRB vertical motion. This yields a first vertical motion at approximately 0.253 second MET.

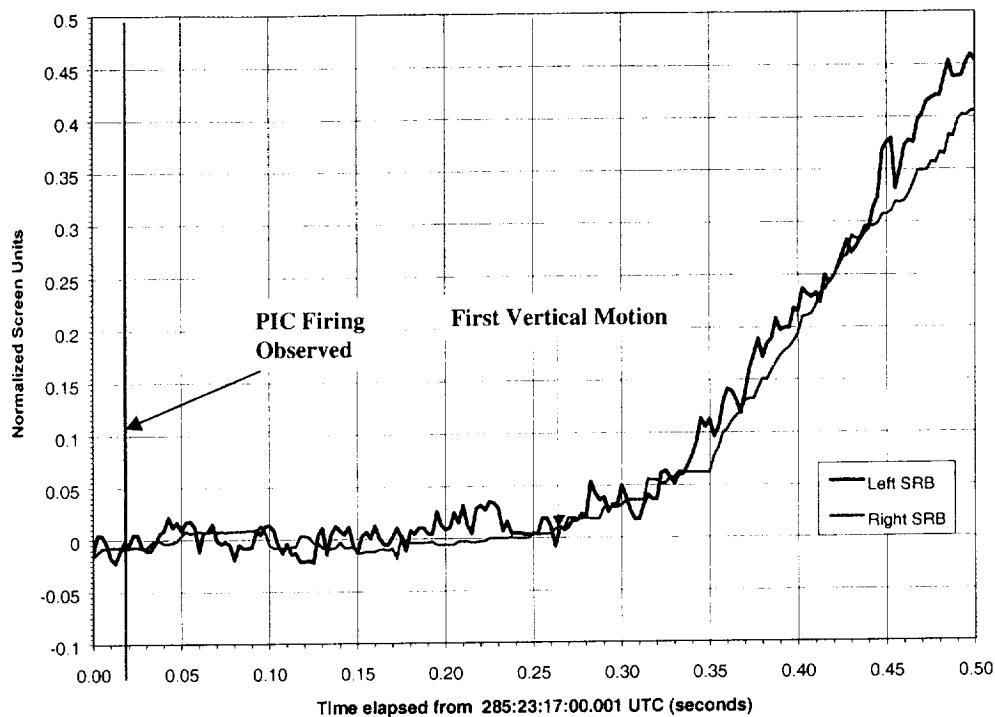


Figure 10. First Motion of STS-92 SRBs

8.2 Cork damage on the Right SRB

Cork damage on the Right SRB at the center field joint protective surface (FJPS) was found on post-launch inspection. Tom Williams/MP51 and Steve Holmes/MP31d asked MSFC Engineering Photographic Analysis to review film and video to determine if debris, which might cause such damage, could be observed in the area near or aft of the joint.

Film cameras E1, E2, E62, E207, E212, E213, and E220 and video cameras ET-207, ET-212, and ET-213 were reviewed in sessions with Mr. Holmes and Mr. Williams.

Haze and darkness from a night launch reduced visibility on many film/video products. Clouds also obstructed the view of the vehicle during portions of the ascent. The visually inaccessible position of the damage site on the SRB also limited possible observations. No debris was observed that could be directly associated with damage at the impact area.

For further information concerning this report contact Tom Rieckhoff at 256-544-7677 or Michael O'Farrell at 256-544-2620.

| REPORT DOCUMENTATION PAGE | | | Form Approved OMB No. 0704-0188 | |
|--|---|--|---|---|
| Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503. | | | | |
| 1. AGENCY USE ONLY (Leave blank) | | 2. REPORT DATE Nov 2000 | | 3. REPORT TYPE AND DATES COVERED Final 4-23 October 2000 |
| 4. TITLE AND SUBTITLE Debris/Ice/TPS Assessment and Integrated Photographic Analysis of Shuttle Mission STS-92 | | | 5. FUNDING NUMBERS OMRS00U0 | |
| 6. AUTHOR(S) Gregory N. Katnik | | | | |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) NASA, John F. Kennedy Space Center Process Engineering, Mechanical Systems Division ET/SRB Branch, Mail Code: PH-H2 Kennedy Space Center, Florida 32899 | | | 8. PERFORMING ORGANIZATION REPORT NUMBER TM-2000-208585 | |
| 9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) | | | 10. SPONSORING / MONITORING AGENCY REPORT NUMBER | |
| 11. SUPPLEMENTARY NOTES | | | | |
| 12a. DISTRIBUTION / AVAILABILITY STATEMENT Blanket Release | | | 12b. DISTRIBUTION CODE | |
| 13. ABSTRACT (Maximum 200 words) A debris/ice/thermal protection system assessment and integrated photographic analysis was conducted for Shuttle mission STS-92. Debris inspections of the flight elements and launch pad were performed before and after launch. Icing conditions on the External Tank were assessed by the use of computer programs and infrared scanned data during cryogenic loading of the vehicle, followed by on-pad visual inspection. High speed photography of the launch was analyzed to identify ice/debris sources and evaluate potential vehicle damage and/or in-flight anomalies. This report documents the debris/ice/thermal protection system conditions and integrated photographic analysis of Space Shuttle mission STS-92 and the resulting effect, if any, on the Space Shuttle Program. | | | | |
| 14. SUBJECT TERMS STS-99 Thermal Protection System (TPS) Ice Debris Photographic Analysis | | | 15. NUMBER OF PAGES | |
| | | | 16. PRICE CODE | |
| 17. SECURITY CLASSIFICATION OF REPORT Unclassified | 18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified | 19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified | 20. LIMITATION OF ABSTRACT Unlimited | |

**DEBRIS/ICE/TPS ASSESSMENT AND INTEGRATED PHOTOGRAPHIC ANALYSIS
REPORT DISTRIBUTION LIST 11/00**

NASA - KSC

MK/J. Halsell
MK-SIO/R. Page
PH-M2/T. Hawkins
PH-H/J. D. Kelley
PH-H2/G. Katnik (7)
PH-P4-B/A. Willett
TA-B2/C. Brown

SK/F. Kienitz
USK-321/R. S. Herman
USK-708/K. Revay
ZK-86/D. Leggett
JCI-VIPC-1/R. Robinson
MMC-15/D. S. Otto
USK-840/L. Clark

NASA - JSC

EP4/P. Cota
ES/G. Galbreath
MV/K. Brown
MV/J. Mulholland
SN3/E. Christiansen
SN3/G. Byrne

Johnson Space Center
Houston, Texas 77058

NASA - MSFC

EE31/J. L. Lusaka
TD53/T. J. Rieckhoff
TD63/J. Sambamurthi
841-ZA12/J. Hixson

Marshall Space Flight Center
Huntsville, AL 35812

Rockwell - Downey

H019-F701 /J. McClymonds
H017-D416 /R. Ramon

The Boeing Company
5301 Bolsa Ave.
Huntington Beach, CA 92647

Lockheed Martin

Dept. 4610/P. A. Kopfinger
MAF Technical Library

LockheedMartin Michoud Assembly Facility
13800 Old Gentilly Road
New Orleans, Louisiana 70129